FINANCE MINISTRY

SURVEY DEPARTMENT, EGYPT.

THE PHYSIOGRAPHY OF THE RIVER NILE AND ITS BASIN

BY

CAPTAIN H. G. LYONS,
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Note I.—The black portion of each river section represents the section drawn to the same vertical and horizontal scale.

" **II.**—Names of places in Egypt and the Sudan are written as in the published Government maps. The systems are practically identical except that the arabic word for a hill is transliterated as Gebel in Egypt and Jebel in the Sudan. In Egypt the letter ق is transliterated by q.

THE

PHYSIOGRAPHY OF THE RIVER NILE AND ITS BASIN.

CHAPTER I.

Almost 50 years ago von Klöden published his "Das Stromsystem des oberen Nil"[1] in which he summed up the hydrography of the river, so far as it was known at that date, with a greater wealth of detail than had been done before. Eight years later Lombardini communicated to the Institute of Milan the paper afterwards published as "Essai sur l'Hydrographie du Nil",[2] in which he utilised the additional information which had accumulated since von Klöden's work, especially the discovery of the equatorial lakes by Speke and Grant in 1862. In this brilliant memoir he broadly outlined the principal facts of the regimen of the river in so masterly a way that the improved data of more recent times have in most cases only borne out his earlier generalisation. Chavanne[3] in 1885 compiled a description of the Nile in which the surveys of the Bahr-el-Jebel and the Victoria Nile by General Gordon and his staff, and the observations of Emin, Schweinfurth, Junker, and others, were utilised to complete the description of the river. Chélu in 1891[4] dealt very briefly with the whole of the Blue and White Nile systems south of Khartoum. In 1897 de Martonne[5] described the hydrography of the basin of the Upper Nile, but did not deal with the basin of the Blue Nile. This valuable paper brought together all previous observations on the equatorial lakes and the surrounding country, as well as the basins of the Bahr el Jebel, the Bahr el Ghazal, and the White Nile, but owing to the Mahdist rebellion in the Sudan, little new information had for ten years past been obtained from the basin of the White Nile and its tributaries. The works of von Klöden, Lombardini and de Martonne summarize then the hydrography of the Upper Nile up to

[1] Berlin, 1856.
[2] Milan, 1865.
[3] "Afrika's Ströme und Flüsse," Wien, 1883.
[4] "Le Nil, le Soudan, l'Egypte," Paris, 1891.
[5] "Zeitschrift für Erdkunde 5." Berlin, 1897.

1856, 1886 and 1896 respectively. By the second of these dates the general regimen of the Nile and its tributaries was known, and the work of the next twenty years has been mainly that of filling in the details of the general plan.

With the fall of Omdurman in 1898 a new stage in the study of the Nile commenced. As posts were established further south, river gauges were erected, and a more precise knowledge of the periodical rise and fall of the river was obtained; in 1901 Sir W. Garstin published a report[1] on Irrigation Projects for the Upper Nile, in which a series of accurate measurements of various tributaries was given, while the volumes discharged by the Blue and White Nile and the Atbara river were measured frequently in 1902 and 1903, and also those of the tributaries of the White Nile in the dry season of 1903, and the rainy seasons of 1902 and 1903.

In 1904 Sir W. Garstin published a further report on the basin of the Upper Nile[2] in which the White Nile basin was dealt with in great detail and all recent hydrological data were included. Together with this, a report by Mr. C. E. Dupuis on lake Tsana on the Abyssinian plateau, and the Atbara river added considerably to our knowledge of the Blue Nile basin. Several recent books and papers on the Nile system have also treated more or less completely of some of its aspects but even the latest of these[3] deals very superficially with the climate, the geology, and the development of the river.

Since 1896, the Uganda administration has made regular observations of the level of lake Victoria, and since February 1904 of lake Albert also, while meteorological stations in these equatorial regions have been largely increased, and in the Sudan observations are now being taken regularly at numerous stations. The geological examination of German East Africa is progressing rapidly, and the results which have been already published give a much fuller knowledge of the structure of the lake plateau than has hitherto existed. In Uganda new data of this class are few, but in the Sudan a good deal of preliminary work has been done, so that we may now trace, though imperfectly, some of the more important structural features of the area.

Hitherto, the source of the Nile supply, its amount, its periodicity, the possibility of increasing it at low stage, and of guarding against dangers of excessive floods have been the special points of the river regimen which have received attention. The story of Egyptian irri-

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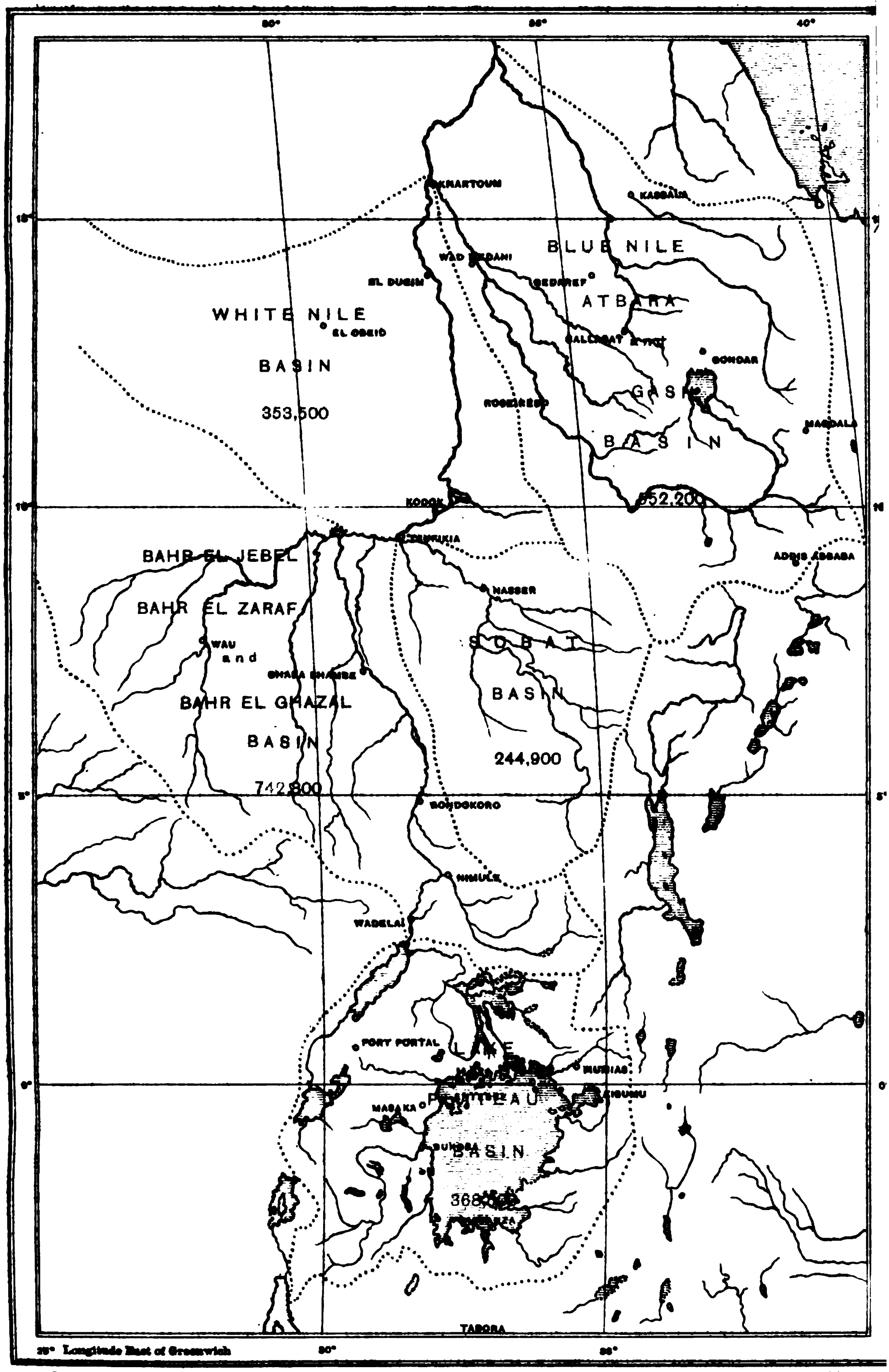
[1] Blue book. Egypt No. 2, 1901.
[2] Cairo, 1904, and Blue book, Egypt, No. 2, 1904.
[3] The Nile in 1904, London, 1904.

THE BASINS OF THE UPPER NILE

PLATE I.



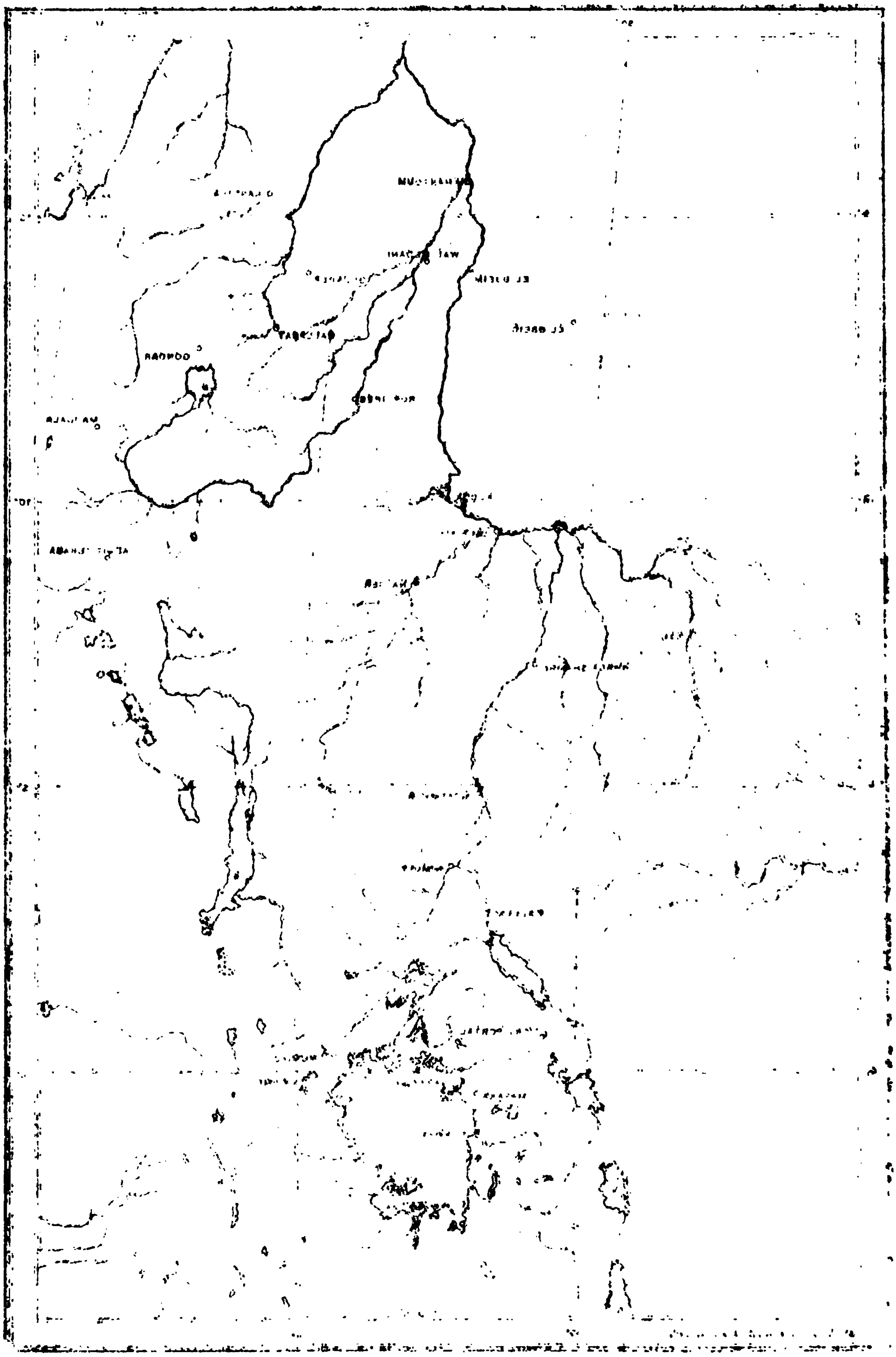
Survey Dept. Cairo.

Note Figures in red denote areas of basins in square Kilometre

Scale 1 : 12.000.000

PLATE I

THE BASINS OF THE UPPER NILE



gation, its reorganization and development in recent years has attracted many writers, and the annual reports of the Public Works Ministry of Egypt as well as the works of Willcocks,[1] Chélu,[2] Brunhes,[3] and Barois,[4] to mention a few only, contain full and detailed accounts of the utilization of the waters of the Nile. The more strictly geographical treatment of the subject has of late years received less attention than the utilitarian, since the earlier period of exploration and discovery came to an end to be succeeded by one in which more accurate and detailed investigation is needed; at the same time the results of geographical study can greatly assist the practical development of the resources of the river basin, and can furnish clues for the elucidation of doubtful points by bringing to aid the results of meteorological and geological research by which the physical development of this part of the continent may be traced. It is desirable, therefore, that the hydrography of the Nile should be described in the light of this information, so as to furnish an account of this great river and its tributaries, defining the part that each plays in the regimen of the whole river system. By this means we may hope to learn in which direction work may most usefully be done in order to attack the many problems which still remain awaiting solution, although a high civilization has existed on the banks of the Nile for more than 6000 years, and since the first dynasty of the ancient empire of Egypt, at least 3600 B.C., the height of the flood has been annually recorded as the most important event of the Egyptian year.

But much of this information is not readily accessible, even in Europe; observations are buried in papers communicated to different societies, or lie in government reports which are not easily obtainable, and in the following pages many such sources of information have probably been overlooked although every endeavour has been made to render the references to authorities as complete as possible. Still it is hoped that this collection of material furnished by many travellers, explorers and investigators in the Nile Basin, may be of service both to those whose work is directly connected with the River Nile, as well as to geographers who are studying the phenomena of great rivers.

In the following pages the Nile basin will first be discussed as a whole, and the general lines of its geology, its climate and its hydrography, which together comprise its physiography, will be briefly

[1] "Egyptian Irrigation," 2nd edition, London, 1899.
[2] "Le Nil, le Soudan, l'Egypte," Paris, 1891.
[3] "L'irrigation dans la péninsule ibérique et dans l'Afrique du Nord," Paris, 1902.
[4] "Les irrigations en Egypte," Paris, 1904.

sketched. A more detailed description on similar lines will then be given of the principal drainage basins, viz:—the lake Plateau, the Bahr-el-Jebel, Bahr-el-Zaraf and the Bahr-el-Ghazal, the Sobat river, the White Nile and the Blue Nile and Atbara. These collect the rainfall which occurs from month to month in the different tributary basins and so supply the Nile in its long course through the desert region of the Sudan and Egypt.

Below Berber the river receives no addition to its supply except that which drains back into it at low stage from the soil of the flood plains, in which the saturation level caused by the summer flood is still higher than the river level, and the occasional "seils" or floods which pour down the desert valleys as the result of the rain storms which occur at long intervals on the desert plateau. But these are of small effect, and in its passage through the desert area north of lat. 18° to the sea the Nile is losing water rapidly by evaporation in a climate where conditions of extreme dryness persist throughout the year, and the north-east trade-wind blows almost without intermission. No accurate data yet exist by which this loss can be measured, and the evaporation values usually quoted are unsatisfactory.

From Aswan to the sea the river and its valley have been fully described in the numerous works on irrigation which have been published, but it will be useful to examine the evidence on certain points in the light of more recent information; among such may be mentioned evaporation, rate of deposit of silt, both in the river bed and on the flood plains, and the alleged modification of the climate as a result of increased irrigation.

The Nile basin comprises an area of about 2,900,000 square kilometres, which lies between the 4th parallel of south latitude and the 32nd parallel of north latitude, thus extending over about 3,100 kilometres from south to north; but only a portion of this vast extent is an effective area since the whole of Darfur, Kordofan, the Bayuda desert, and all the deserts north of Berber contribute nothing to the river supply. The limits of the basin are now accurately known, and mapped with sufficient precision for the purposes of the present study.

Dimensions of the Nile and its basin.[1]—The length of the Nile is usually given[2] as 5400 kilometres (3355 stat. miles) to the centre of Lake Victoria, or 6000 kilometres (3728 stat. miles) for the

[1] "Geog. Jour." Aug. 1905.
[2] Wagner, "Lehrbuch der Geographie," p. 417. Hanover: 1903.

continuous waterway from the source of the Kagera to the sea; the area of its basin is given as about 2,900,000 square kilometres (1,119,737 square miles). These measurements have hitherto been made on small-scale maps, but since a considerable part of the upper Nile has been recently surveyed on 1 : 250,000, or a larger scale, and numerous points in its course have been fixed astronomically and by triangulation, it is now possible to measure its length sufficiently accurately to furnish a value which later surveys probably will not materially alter.

In the following table the results of such a measurement are set forth together with the maps used. The measurements were made with a curvimeter,[1] and the mean of four concordant readings were taken. The centre line of the river was followed as far as possible, and round islands the wider arm. The measurements were made

TABLE OF DISTANCES ON THE RIVER NILE.

	Place.	Distance.		From Ripon falls.		Authority.	Scale.
		Km.	Miles.	Km.	Miles.		
Victoria Nile.	Ripon falls...	—	—	—	—	Intell. Dept. W. O., Map No. 1429.	$\frac{1}{633600}$
	Kakoji...	64	40	64	40		
	Mruli	135	84	199	124	Survey by Captain R. Owen. Cf. *Geographical Journal*, March, 1905.	$\frac{1}{190080}$
	Foweira	75	47	274	170		
	Murchison falls...	77	48	351	218		
	Albert lake...	38	24	389	242	Colonel Delmé-Radcliffe, *Geographical Journal*, Feb. 1903.	$\frac{1}{500000}$
Bahr el Jebel.	Bahr el Jebel entrance ...	3	2	392	244		
	Wadelai	64	40	456	283		
	Nimule	152	94	608	378		
	Asua river...	21	13	629	391	Sir W. Garstin, 1903.	$\frac{1}{1000000}$
	Fort Berkeley	126	78	755	469		
	Gondokoro...	32	20	787	489		
	Lado	12	7	799	496		
	Mongalla	29	18	828	515	Captain H. G. Lyons, 1901 and 1903, adjusted to positions determined by Colonel Hon. M. G. Talbot, R.E.	$\frac{1}{80000}$
	Bor	134	83	962	598		
	Kenisa...	117	73	1079	670		
	Ghaba Shambé...	80	50	1159	720		
	Hellet Nuer	181	112	1340	833		
White Nile.	Lake No	208	129	1548	962		
	Taufikia	132	82	1680	1044		
	Dueim...	630	391	2310	1435		
	Khartoum	200	124	2510	1560		
Nile.	Shendi...	186	116	2696	1675		
	Atbara river	139	86	2835	1762	Topographical Division, General Staff. No. 1489	$\frac{1}{250000}$
	Berber...	40	25	2875	1786		
	Abu Hamed	208	129	3083	1916		
	Merowe	240	149	3323	2065		
	Dongola	272	169	3595	2234		
	Wadi Halfa	445	277	4040	2510		
	Aswan...	345	214	4385	2725		
	Luxor...	219	136	4604	2861		
	Qena	64	40	4668	2901		
	Girga	124	77	4792	2978		
	Assiut...	141	88	4933	3065		
	Cairo	397	247	5330	3312		
	Delta Barrage	23	14	5353	3326		
	Rosetta mouth...	239	147	5589	3473	Total length, 5589 kilometres or 3473 miles.	

[1] By Coradi, of Zürich.

SOURCE OF KAGERA TO RIPON FALLS.

Place.	Distance.		From source.		
	Km.	Miles.	Km.	Miles.	
Source	—	—	—	—	
Kagera mouth ...	690	429	690	429	Karte von Deutsch Ost-Afrika.[1] Reimer, 1895. 1 : 300,000.
Ripon falls	218	135	908	564	Chart of Lake Victoria, by Com. B. Whitehouse, 1900-1.

Length of continuous waterway, 5589 + 908 = 6497 kilometres or 4037 miles.

in kilometres, and were corrected for instrumental errors and map shrinkage.

The distances below Wadi Halfa are those generally accepted.[2] A new triangulation has just been completed from Damietta to Wadi Halfa, and the publication of a general map of the Nile valley and delta on the scale of 1 : 50,000, based on the Revenue Survey maps of 1 : 2500 and 1 : 4000, has been commenced; as soon as these map sheets are ready, improved values for this distance will be obtainable, but it is not anticipated that those given above will be much altered.

The area of the Nile basin is given by Bludau [3] as 2,803,000 square kilometres (1,082,284 square miles) composed of 2,660,000 square kilometres (1,027,069 square miles), representing the area known to drain to the Nile, and 143,000 square kilometres (55,215 square miles) to the west of Lake Rudolf and south of the Sobat river, which was then unexplored. Taking this as the most recent value, it may be compared with a more complete estimate, which the recently published maps of the Sudan permit.

For determining the area of the catchment basin, the larger-scale maps which were used in measuring the length of the river are not necessary, for over almost all the basin there is a very small amount of topographical detail, so that the watershed between the different river-basins can only be approximately indicated. The area has therefore been calculated from a map on the scale 1 : 4,000,000 [4] for the Sudan and Uganda, and from one of 1 : 2,000,000 [5] for Egypt. The

[1] As modified by Dr. Kandt, Caput Nili, Berlin, 1905.
[2] Willcocks, "The Nile in 1904," Tables vii., viii. London: 1905.
[3] *Pet. Mitt.*, 1897, p. 184.
[4] I.D.W.O. Map, No. 1856, extended southwards to include the Victoria lake and its catchment basin.
[5] Topog. Div. Gen. Staff, 1905, No. 1792.

proportion of each square degree belonging to each basin was determined by measurement on the maps, and the area in square kilometres deduced from it. The results are given in the following table:—

AREAS OF CATCHMENT BASINS.

Name of basin.	Area in square kilometres.	Area in square miles.
Victoria lake	238,900	92,243
West valley[1]	54,100	20,889
Victoria Nile	75,600	29,190
Bahr el Jebel[2]	190,700	73,632
Bahr el Ghazal	552,100	213,175
Sobat river	244,900	94,560
White Nile	353,550	136,492
Blue Nile...	331,500	127,998
Atbara	220,700	85,216
Nile	605,600	233,832
Nile	2,867,600	1,107,227

The area of the basin will vary according to the distance to which its limits are considered to extend on the west of the Nile northwards from Dongola. It has here been taken as far as the cliff of the desert plateau, or the first marked rise of the desert where the cliff is absent, probably, on the average, about 3 to 4 kilometres from the edge of the cultivation in Egypt. The whole of the Nile basin below Khartoum, and practically all the White Nile basin, are non-effective in increasing the river-supply, since the occasional local cloud-bursts may be neglected. The Bahr-el-Ghazal, as has been shown by recent measurements of the volume discharged, is also practically non-effective.

All measurements have been made in the metric system, and the "rounded off" values converted to miles and square miles.

Limits of basin.—Taking the head waters of the Kagera river near the north-east angle of Lake Tanganika as a starting point,[3] the western limits of the basin pass westward by the volcanoes of Kirunchanga and Mfumbiro, between lakes Kivu and Albert Edward, along the western side of the trough in which these lakes and the Albert lake lie, then turning north-west near Wadelai along the watershed between

[1] Including the basins of Albert Edward and Albert lakes, and the Semliki river.

[2] Including the Bahr-el-Zaraf.

[3] Plate I.

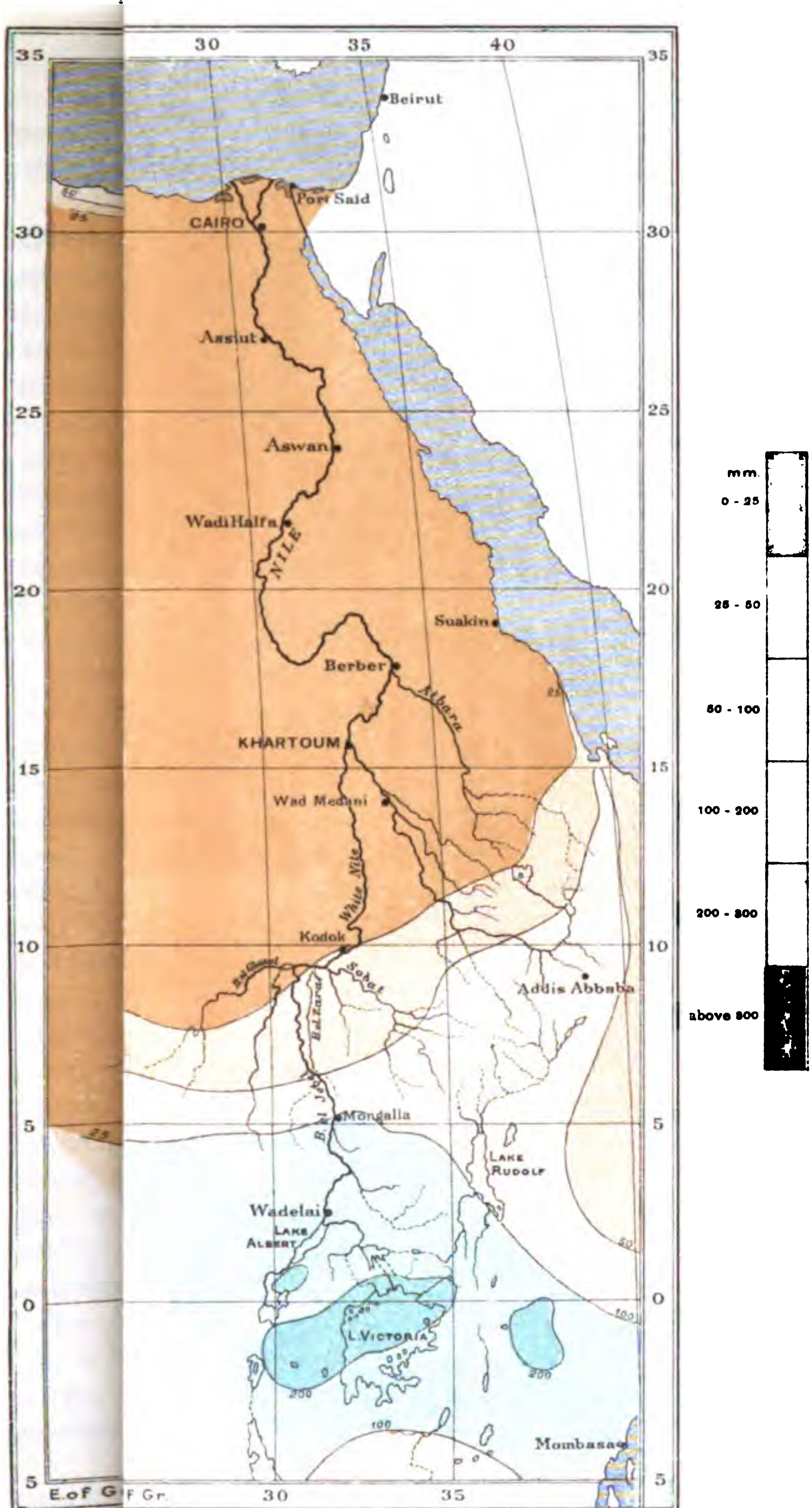
the tributaries of the Congo and those of the Bahr-el-Ghazal as far as the Marpa hills of Dar Fertit. The line now turns northwards through the Marra mountains of Darfur, and then north-eastward to near Dongola from which point it runs parallel to the river and usually from 10 to 30 kilometres from it until the Delta is reached.

The eastern limit has a straighter course and passing a short distance to the south of lake Victoria turns northward along the Nandi hills to mount Elgon and thence along the ridge of high land on the west of lake Rudolf. From this point it follows a somewhat devious line across the plateau of Kaffa and Wallega, dividing the head waters of the Omo and the Hawash from those of the Sobat and the Blue Nile, to near Addis Abbaba, when it turns northwards along the eastern crest of the Abyssinian table-land as far as lat. 15° N.; from this point it turns westwards to Kassala, and thence follows the ridge of high land which runs parallel to and near the Red Sea and the Gulf of Suez.

The main features of the Nile basin are: firstly, the plateau of the equatorial lakes which has an average altitude of about 1300 to 1500 metres besides the mountain range of Ruwenzori and the volcanic mass of Elgon which rise some 5000 and 2000 metres higher respectively; secondly the watershed, about 800-900 metres above sea level which separates the Bahr-el-Ghazal basin from those of the Congo and lake Chad; thirdly the Abyssinian table-land which is more than 2000 metres above sea-level; and fourthly the vast tract of country, less than 500 metres in altitude, which extends from near Hofra-el-Nahas in the upper reaches of the Bahr-el-Arab in Kordofan, and Gondokoro on the Bahr-el-Jebel, to the Mediterranean.

The geography of the basin is now known with considerable accuracy, and reliable maps of almost the whole of the Sudan are already published, as well as of much of Abyssinia; Junker's and Schweinfurth's work in the Bahr-el-Ghazal was added to by the Marchand expedition, and recently the numerous surveys and reports of the officers of the Egyptian Army have largely increased our knowledge of this part. Of the upper reaches and tributaries of the Bahr-el-Arab little is yet known, and even with Emin Pasha's journeys to the east and south-east of Gondokoro and Wadelai, supplemented by the expeditions of Colonel Macdonald, Dr. Donaldson Smith, Comte Bourg de Bozas and others, there is still much to be learned about the northern part of the great lake plateau. Uganda, and the districts which border it, are known in their broader features, and their lake and river systems have been examined. From the point of view of the Nile supply it

APRIL PLATE IIa.



Survey

may fairly be said that a practically constant supply between Mruli and Foweira on the Victoria Nile, and a variable supply at Wadelai depending upon the level of the Albert lake, sum up the rôle of the equatorial lakes to-day as reservoirs feeding the Nile.[1]

Geology.—The structure of the different parts of the basin, and particularly of the lake plateau and of the Abyssinian table-land is important as controlling the main drainage lines, but geological examination has been confined to a few areas, and almost the only detailed work is that of Dantz and Hermann to the south and south-west of lake Victoria. Here we meet with a vast plateau of granitoid gneiss, overlaid in places by schists, and frequently covered thinly by a ferruginous laterite deposit, the result of the weathering of the underlying crystalline rocks in a tropical climate. This gneiss is the predominant rock throughout Uganda, though to the north-east of the lake volcanic rocks occur, and in mount Elgon we have the huge cone of an extinct volcano. Further north it forms the hills in which the Asua and other rivers rise; it crops out frequently in the Bahr-el-Ghazal wherever the natural rock appears through the surface soil and alluvial deposits, and to the east it passes under the thick volcanic series of the Abyssinian table-land. North of the line where this plateau of the equatorial lakes slopes quickly to the vast alluvial plains of the Bahr-el-Jebel, the Sobat and the White Nile, a few isolated hills of this rock, more or less granitoid in character, occur, as Jebel Zaraf close to the mouth of the Zaraf river, and Jebel Atin on the Pibor, probable outliers showing the former extension of the lake plateau, with which, no doubt, at some remote period the hills of Kordofan and the ridge of granitoid hills of the Gezira were connected; now they remain as the low worn-down stumps of ancient mountain groups, and in the Gezira divide the basin of the White Nile from that of the Blue. The Kordofan ridge being in an area of feeble precipitation serves only as the radiation point for a number of drainage lines, which carry a certain amount of water in the rainy season but usually lose themselves in a swamp or a sandy depression before reaching the main stream.

The Abyssinian table-land is composed mainly of a vast block of basalt lava, which has been poured out in places to a thickness of some 2000 metres, and overlies the gneiss and crystalline schists, as well as certain sedimentary deposits. North of Khartoum, for some ten degrees of

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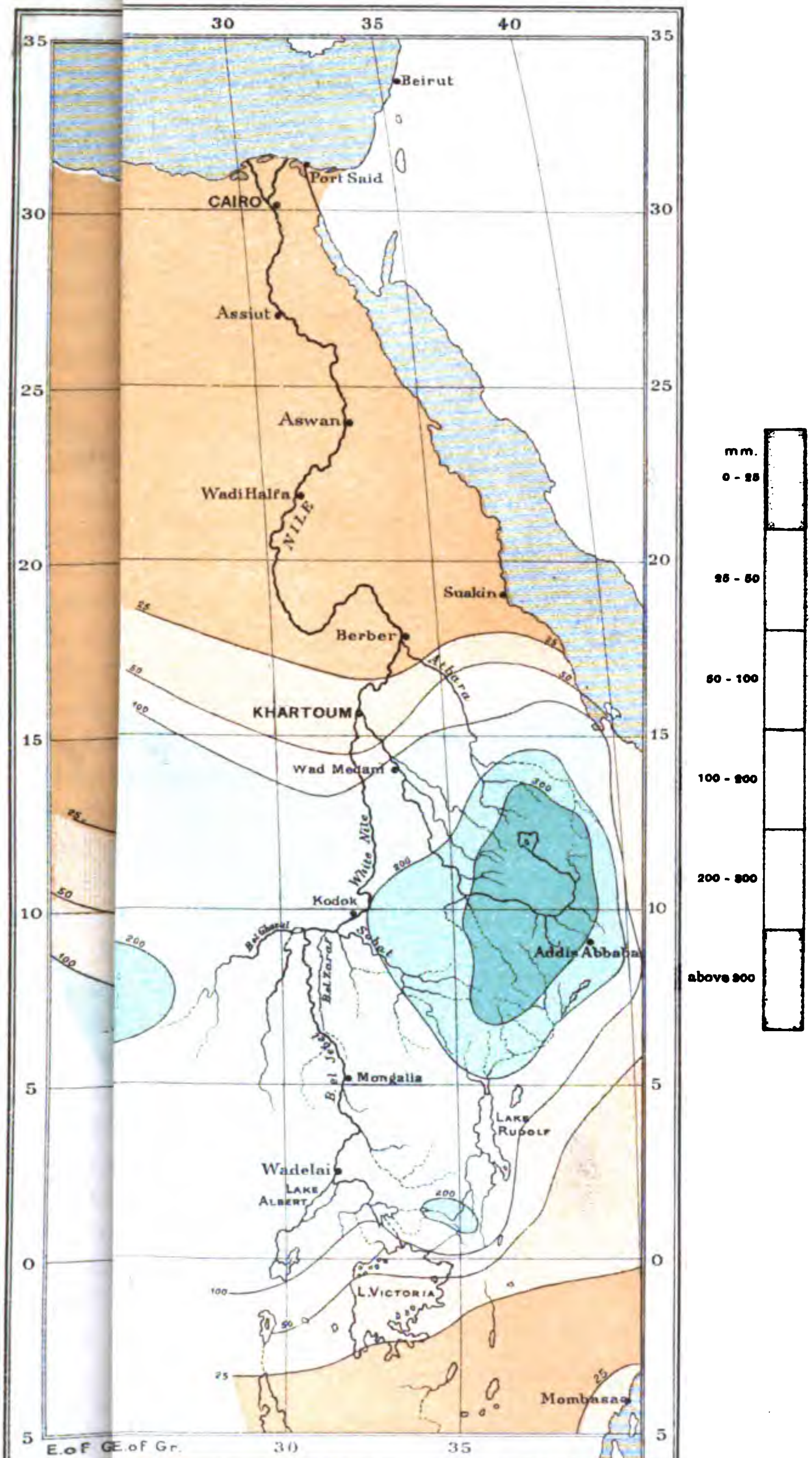
[1] See p. 62 and p. 77.

latitude, reddish and brownish sandstones overlie more or less thickly the old land surface of crystalline rocks of various kinds, the gneisses of archaean type, the later granites and schists, as well as a volcanic series of immense thickness and of very early age. Long-continued erosion has removed much of the overlying sandstone, which, however, never covered the higher parts of the crystalline ridge on the eastern side of the basin, but was laid down on its flanks. The Nile therefore reaches these underlying harder rocks at many points where they now offer resistance to its erosive action, and form the numerous rapids which are known, not very accurately, as the cataracts of the Nile. The factors which determined the present course of the Nile through the northern Sudan will not be known until a more thorough geological examination of this part is carried out than has yet been made, but it is of interest to note that between Korosko and Aswan, wherever the crystalline rocks occur, the direction of the river is closely parallel to that of the intrusive dykes. [1] North of Edfu the river occupies a trough between cliffs which rise to the level of the limestone plateau some 300 to 500 metres above the valley floor, and here parallel faults have let down this strip of country, thus determining the drainage line which the Nile now follows, and in which it has for thousands of years deposited its silt on the sands and gravels which had previously been laid down in it. Here the river is scarcely ever eroding the rocks of the plateau, but flows in its own flood plain so that the geological structure of this part of the continent no longer exerts a direct influence upon the river.

Climate.—In the high pressure zone situated 30° to 35° north and south of the equator, there is a gradual settling down of the atmosphere towards the earth's surface, and its humidity becomes gradually less, until the air reaches the earth's surface warm and dry. In its subsequent passage over the 20° of latitude of the hot trade wind belts, it takes up moisture and carries it forward into the equatorial calm-belt, a region of low atmospheric pressure. Here it is carried up by the ascending air currents, and its moisture is condensed into clouds and rain. Thus it is that the equatorial calm-belt is also a cloud-and rain-belt, being supplied with the necessary moisture by the north-east and south-east trade winds. The rain-belt is wider and less defined than the calm-belt, since the ascending air currents flow outwards as they gradually expand and diverge from the central line of the calm-belt.

[1] Ball. Geol. of Aswan Cataract, in the press.

AUGUST PLATE IIb.



As this condensation is constantly taking place in this equatorial belt, it follows that the greatest precipitation will be in the neighbourhood of the centre of the belt, as it moves northwards and southwards in its annual oscillation, a change determined by the position of the sun at noon, since where it is in the zenith at noon, it will have the greatest heating effect, causing the ascensional movement of air above referred to. A place situated in the mean position of the belt will have its heaviest rainfall in April and October, with minima in June and December, when the rain-belt centre is at the greatest distance north and south of it; if the rain-belt is narrow, dry seasons may even be experienced at these months. Similarly a place situated to the north of the equator, within the limits of the oscillation of the rain-belt, will have a single rainy season in the summer of the northern hemisphere, followed by a long dry season throughout the rest of the year.

In the Nile basin this equatorial rain-and calm-belt has its mean position about lat. 1° N., where there is an almost continuous rainfall with maxima in April-May and in November. As it moves northwards the summer rains of the southern Sudan set in, which gradually extend northwards to the valley of the White Nile and the high table-land of Abyssinia.

Besides the general circulation of the atmosphere, there are certain periodical alternations of direction and velocity, which in some parts of the world play an important part in the climatology of the area. The diurnal alternations are such as the land and sea-breezes, or valley and mountain winds; the annual alternations are the monsuns. These latter blow for six months of the year from one direction, and the other six months from the contrary direction but owing to the disturbing effect of other air currents, and to deflection by mountain ranges and such topographical features, such complete reversal is only strongly marked in certain regions.

In India and the north Indian Ocean conditions are exceptionally favourable to the development of summer monsun winds, and here the most typical case is found.

In north-east Africa there is a monsun effect over the Sudan and Abyssinia, which manifests itself principally between the latitudes of lat. 5° N. and lat. 18° N., as an alteration of northerly and southerly winds in the dry and wet seasons respectively. During the months of June, July, August, September and October southerly winds predominate which are the south-easterly trade winds of the southern hemisphere becoming southerly at the equator and south-westerly further

north, owing to the deflecting force of the earth's rotation, and to the low pressure area then lying over Arabia and Abyssinia. During the rest of the year the north-easterly trade-winds, more northerly on land where there is more friction, blow down to lat. 5° N. This reversal is due to the oscillation to and fro of the equatorial calm-belt already described.

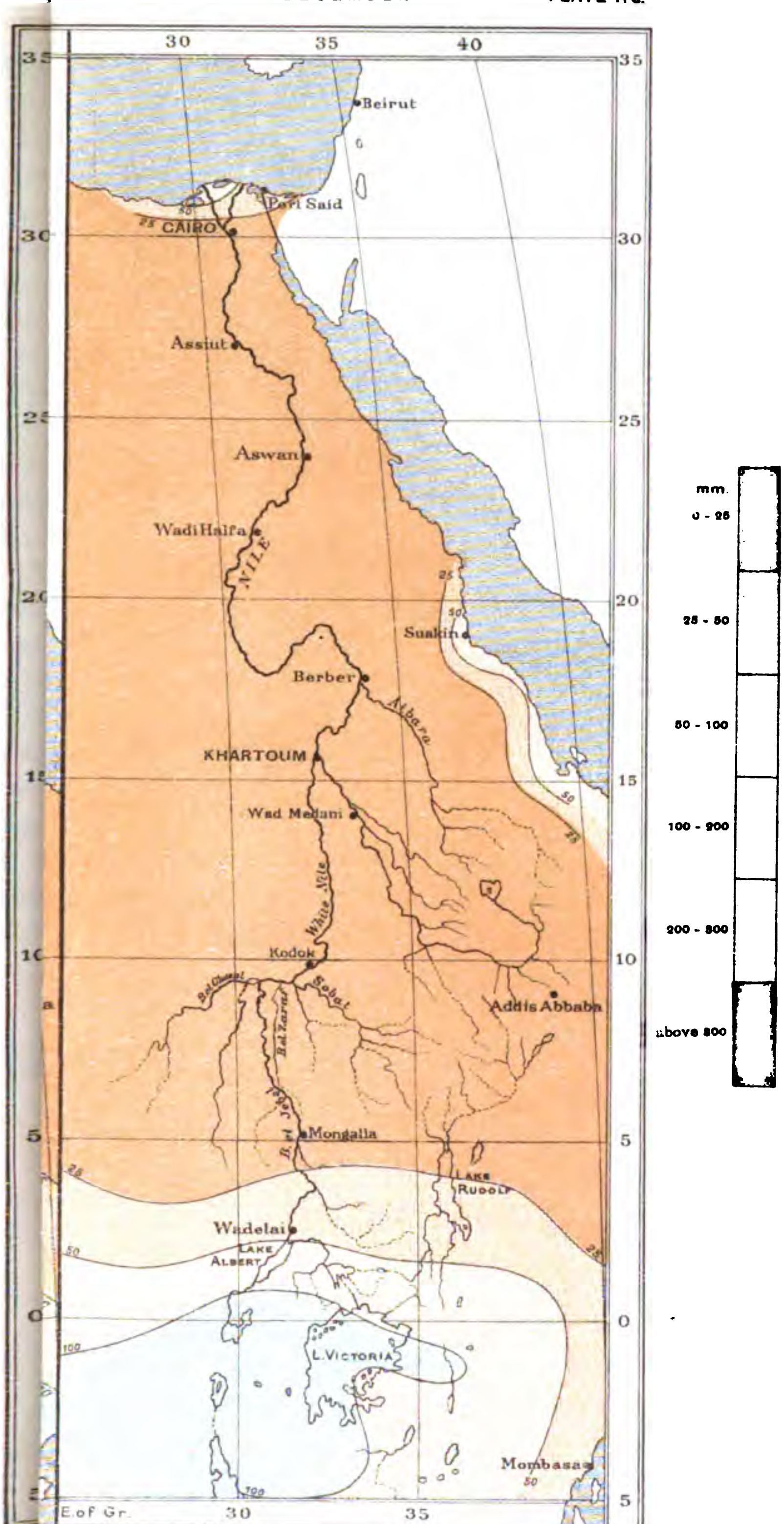
The lake plateau, from its situation on the equator, receives a moderately heavy rainfall, which is distributed in two rainy seasons March-May and November-January, but these are not very sharply defined, and some rain falls in most months of the year, especially in the neighbourhood of the Ruwenzori range; it is more convenient therefore to consider that there is a pronounced dry season in July and August, and a lesser one in February, the heaviest precipitation taking place about May and December.[1] Further north conditions approach those of tropical rains, one wet season and one dry season corresponding more or less with the summer and winter solstices, so that in the basins of the Bahr el Ghazal, Bahr el Jebel and Sobat there is a rainy season from April to October, while the remainder of the year is comparatively dry, especially December, January and February.

Beyond the 9th parallel of north latitude the rainy season is shorter and more sharply defined, and in the Sudan plains, and on the greater part of the Abyssinian table-land, the rains occur between May 15 and September 15, beginning and ending with great regularity. The effect of this distribution of rainfall is reproduced in the rise and fall of the different rivers; the lake plateau with its almost continuous precipitation furnishes to the White Nile a constant supply which has dwindled to about 400 cubic metres per second by the time it has passed the marshes of the Bahr-el-Jebel, while from the Abyssinian table-land comes the Nile flood with its rapid but regular rise and fall, due to a rainfall no greater than that of the lake plateau but falling within a sharply defined period of four months. It will be seen later that the Nile supply is derived almost wholly from the comparatively small portion of its basin which is more than 1000 metres above the sea level.

It has been known for years past that the rainfall on the more elevated parts of its basin supplies the Nile but the statement that melting snows also play a considerable part still lingers,[2] although except for a few streams fed by the melting glaciers of the Ruwenzori

[1] See Plate II for monthly distribution of rainfall.
[2] Ventre Pacha. "Bull. Soc. Khed. Geog.," Cairo 1894, pp. 7, 33, 34, Chélu "Le Nil, le Soudan, l'Egypte." Paris, 1891, p. 22.

DECEMBER PLATE IIc.



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range, no snow water reaches the Nile, and these streams play an absolutely unimportant part in its regimen.

In the recent report on the Basin of the Upper Nile,[1] two facts of primary importance were published, but their bearing on the hydrography of the river does not seem to have been fully realised if the reviews which have appeared may be taken as a guide. The first is the almost constant volume discharged by the White Nile above its junction with the Sobat, and the second is the feeble part which the White Nile plays in the annual flood, less probably than one twentieth of the flood being due to it.

These two facts alone, irrespective of the mass of other classes of data which have become available in the last 20 years, necessitate a readjustment of views which have been usually held as to the relation of the different tributaries to the main stream and to each other.

A fuller description of the Basin of the Upper Nile together with complete hydrographical details will be found in Sir William Garstin's report[1] from which most of the sections of the Nile and its tributaries have been taken. Those of the Bahr el Zaraf (No. 2 Plate XII), and of the Pibor and Akobo (Plate XIV) were measured by Captain H.H. Wilson and are included here by the kind permission of Major General Sir Reginald Wingate K.C.B. The section of the Abai River (No. 4 Plate XXII*a*) is from Petermanns Mitteilungen by the kind permission of the editor. I would also acknowledge the kind permission of the Council of the Royal Society and of the Council of Royal Geographical Society to use papers published in Proc. Roy. Soc., Vol. 76 A., p. 66-86 and in the Geographical Journal, Aug., Sept., Oct. 1905.

[1] Report upon the Basin of the Upper Nile with proposals for the improvement of that river by Sir William Garstin G.C.M.G., Cairo 1904, subsequently referred to as Report on the Upper Nile.

CHAPTER II.

THE LAKE PLATEAU.[1]

Altitude.—The lake plateau has an average altitude of probably not more than 1500 metres, except in the west where the ridge which bounds lakes Kivu and Tanganika rises to a height of 2500 metres, while the Ruwenzori range, between lakes Albert Edward and Albert, may reach 5500 metres; the east of the main plateau, the Nandi hills, mount Elgon and the Karamojo hills, west of the Rudolf lake, all rise to heights considerably above 2000 metres. On the western side of the plateau, in a great trough, lie the Albert Edward and Albert lakes, and the Semliki river which connects them, but at an earlier period there is no doubt that this trough valley was continuous with the southern portion in which lakes Kivu and Tanganika lie, though now the earth-movements and out-pourings of ash and lava which took place in connection with the volcanic outburst north of lake Kivu, have partially filled the valley at this point, and turned the drainage in opposite directions. The remainder of the area drains into the Victoria lake, which occupies a comparatively shallow depression in the eastern part of the basin.

Limits of the basin.—The basin of the Lake plateau comprising an area of 238,900 square kilometres, is sharply defined on the west by the western cliff of the valley in which lakes Albert Edward and Albert lie; on the south the boundary of the basin crosses this valley by the volcanic range north of the Kivu lake, and then turns parallel to the eastern shores of lakes Kivu and Tanganika following the crest of the valley wall as far as lat. 4° S. when it turns to the north-east to within about 20 kilometres of lake Victoria. From this point it keeps roughly parallel to the southern shore of the lake, bending round the south-eastern corner about 100 kilometres from its shore, and running north-east to the crest of the western scarp of the eastern rift valley.

Except at the north-east, west and south-east limits the differences of altitude are not great throughout the basin. The Victoria lake surface is 1129 metres[2] above sea level, and on the north side the land surface, only 10 or 15 kilometres from the lake shore, falls northwards to

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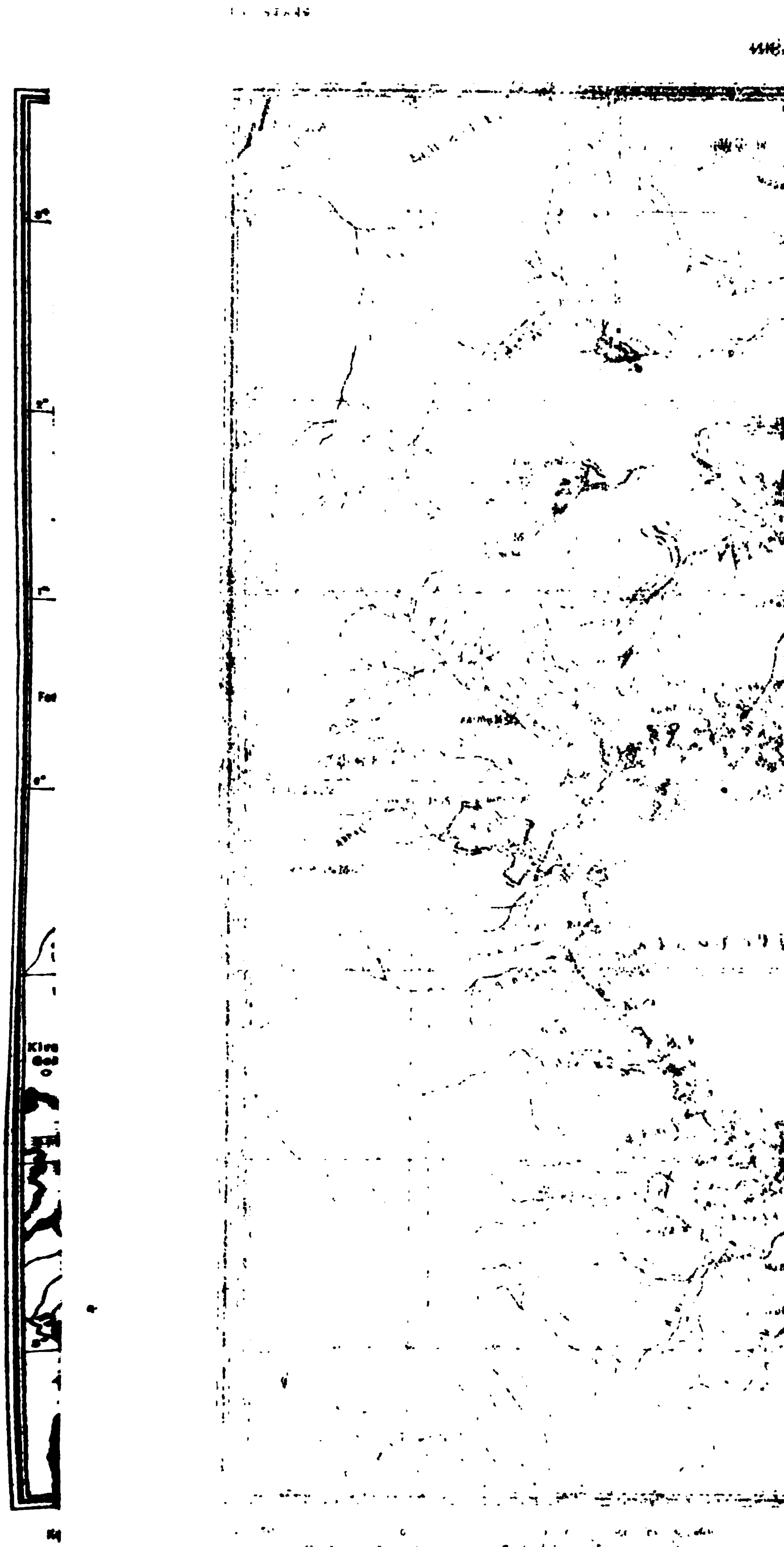
[1] Plate III.
[2] Uganda Railway Survey.



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the Victoria Nile, which at lake Choga is about 1065 metres above the sea; below this the Victoria Nile falls at first gently, then rapidly, to the Albert lake, which is at an altitude of about 700 metres. To the north-east mount Elgon rises as an isolated volcanic mass to a height of 4600 metres, and the western wall of the valley in which lakes Baringo and Naivasha lie reaches the height of 2500 metres above sea level; but to the south of the Mau plateau there extends a rolling open country which only rarely reaches 1750 metres (as at the head waters of the Simiyu river), and usually varies between 1200 and 1400 metres until near the mountain ridge above lake Tanganika, in which the sources of the Kagera river are situated. The western part of the basin is rather higher, ranging from 1400 to 1600 metres and rising occasionally to more than 2000 metres. Further north some of the peaks of the Ruwenzori range are believed to reach 5500 metres, but with the exception of this hill mass no considerable altitudes occur. To the north of the Victoria lake the ground falls gradually to the Choga and other lakes which receive the drainage of mount Elgon and of the country immediately to the north of lake Victoria, and beyond this the the country drains to the north to Foweira and then westwards to the head of the Albert Lake.

Geology.—To the west of lake Victoria Herrmann[1] describes the region as one composed principally of quartzite and clay-slate, which rises considerably above the granite and gneiss area to the south and east, being bounded by a marked drop of from 100 to 450 metres. The lower beds present a great variety of clay-slates which vary from a fine white to a hard black slate. According to him the movements of upheaval have acted along NNE.–SSW. directions, and the intensity seems to have been most marked in the south-western part of the area, not far from the Virunga group of volcanoes of lake Kivu. Five main blocks may be recognized which are separated by troughs; the islands of the western coast of the Victoria lake represent the first of these, while three others range one behind the other between the lake shore and the valley of the Kagera, and in the intervening troughs lie lakes, swamps, or slowly flowing rivers; the fifth forms the Ruanda plateau west of the Kagera. The edges of these blocks have as yet been but little modified by weathering so that the latest movements would appear to be comparatively recent.

[1] "Mitt. aus den deutschen Schutzgebieten," Berlin 1899, p. 3.

Scott Elliot[1] describes the Karagwe and Ankoli districts to the west of lake Victoria, as being some 250 metres higher than the plateau near the lake, and being cut up by meandering valleys; their floor has usually but little slope, and is frequently occupied by papyrus swamp.

Sir William Garstin[2] describes Buddu province as an undulating plateau extending westwards from the eastern cliffs which mark the fault line of this part; gravel deposits and caves occur more than 100 metres above the lake, but these will probably prove to be the result of river action rather than marking a former high level of the present lake. In Ankoli the country is higher but the same alternation of flat round-backed ridges and broad valleys with but little slope, where swamps and sluggish streams render movement difficult, continues almost up to the western edge of the plateau some 190 kilometres from the Victoria lake. At this point a further rise of the country occurs, the general level being now 2000 metres, with hills rising to 2500, and this continues to the eastern edge of the rift valley above lake Albert Edward. A dense forest belt, "the tropical rain-forest",[3] clothes this strip of high land, and presents its characteristic features of tall straight tree-trunks with great buttresses at the base, while lianes climb in festoons from tree to tree; the sun's rays hardly penetrate through the leafy canopy of the larger trees struggling towards the light, and it is only in the more open portions where they reach the ground that the smaller vegetation is able to flourish.

The wide region south of the Victoria lake consists of an undulating plateau 1200-1300 metres above sea level, from which rise two distinct types of hills. The one occurs as steep rocky cliffs, the other as long ridges of considerable size and of even contour; the former are formed by the granitoid gneiss and usually have an E–W strike and a very steep dip, while the latter consist of the ferruginous quartzite schists which are particularly characteristic of this region, and in some parts south-west of the lake contain gold. South of the lake this schist forms groups of long hill-ridges, and south-west of Emin Pasha Gulf the Akaranga hills consist of the same rock where they are cut by E–W. faults.[4]

The ridges of the quartzite schist are frequently bounded, on one side at least, by fault lines, many of which have a direction from SW.–NE; elsewhere faulting in N–S and E–W directions occurs. The

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[1] A Naturalist in Mid Africa, London, 1896, p. 70.
[2] Report on the Upper Nile, p. 32-39, Cairo, 1904.
[3] Schimper. "Plant Geography," Clarendon Press, Oxford, 1904, p. 284 ff.
[4] Dantz. "Mitt. aus den deutschen Schutzgebieten" XV., 1902, p. 155.

shores of the lake in many places present steep cliffs, sometimes as much as 100 metres high, which cannot be satisfactorily explained by ordinary erosion, and are certainly due to fracturing and differential movement of the rocks. These faults have played an important part in the formation of the lake but the time at which this took place cannot be satisfactorily determined until later deposits than these schists are found.[1]

The area south of the lake is occupied by gneiss, which near Nassa forms ridges having a direction NW.–SE., parallel to the strike of the gneiss; these hills have so steep a face that they must form part of a block left by the sinking of the south-eastern part of the Victoria lake.[1]

The eastern side of the lake is occupied by granitoid gneiss with occasional patches of quartzite schist, but north of Shirati on the east side near Karungu (close to the Anglo-German boundary), from Kiua island to Gurukire bay, a distance of 20 kilometres, there occurs a patch of volcanic rocks, doubtless connected with the large development of these rocks to the north-east of the lake on the Mau plateau, and on the north-west of the lake.[2] Other outcrops of the same rocks occur frequently on the road from Kisumu to Mumias when the granite sometimes projects through it. Near Mumias besides these volcanic rocks granitoid gneiss occurs widely, with occasional developments of the quartzite schists, as at the Wanyara Hills near the Nzoya river. In both north and south Kavirondo there is found also an ironstone breccia.[3]

Scott Elliot[4] describes the granitoid gneiss overlaid here and there by the masses of the schists as forming the northern and north-western part of the lake shore, though here and there deposits of ironstone occur near the lake. The surface of these older rocks is usually covered with a deposit of laterite, a ferruginous deposit produced by the weathering of these rocks under the influence of the moist tropical climate.

The Ruwenzori range appears to consist essentially of a mass of the archæan granitoid gneisses elevated as an orographic block during the earth movements, of which there is so much evidence throughout the rift valleys, while its slopes are formed of mica schists, epidiorites and other rocks.[5] When first discovered by Stanley the range was

[1] Dantz. "Mitt. aus den deutschen Schutzgebieten," XV., 1902, p. 155.
[2] Uhlig. Pet. Mitt. 1904, p. 226.
[3] E.E. Walker, Blue book, Africa 11., 1903.
[4] A Naturalist in Mid-Africa. London, 1896, p. 162.
[5] Scott Elliot, loc. cit., p. 166.

thought to be volcanic, but this has long since been disproved by Stuhlmann, Scott Elliot and other travellers, though the statement that it is a volcanic range still appears in recent books.[1] At numerous places round the range, crater-lakes, hot springs and similar phenomena show that considerable volcanic activity recently existed along the fault lines which bound the range, while on the plateau to the east of lake Albert Edward also crater-lakes are numerous.[2]

The most important factor in determining the orography of the lake plateau has been the earth movements which are indicated by the numerous lines of faulting; and as a result of these movements, large masses, many kilometres long, have been raised, lowered or tilted, and in the valleys formed along the fracture lines, the main drainage lines of the district run. Lake Victoria itself is outlined by such fractures. Stuhlmann[3] records one which follows the western shore of the lake, while others run parallel to it, such as the Kingavassi valley, the Urigi lake, the Muissa river and lastly the valley of the Kagera river. The way in which the drainage north of the Victoria lake flows away from it, points to earth movements having determined the form of the narrow ridge which here encloses the waters of the lake, while at one point, Entebbe, there is definite evidence furnished by the readings of the lake gauge of a slight intermittent fall of the land during the last nine years, which has amounted in all to about 80 centimetres.[4]

From the disposition of the gulfs and islands of this part, fault lines appear from Whitehouse's chart to run generally NW.–SE. and NE.–SW. Murchison Bay, Napoleon Gulf, and the Kavirondo coast by Ugowe, being parallel to the first direction, while the islands by Entebbe, the Sesse Islands and Rosebery channel follow the second. Probably Kavirondo Gulf, when it has been studied, will be found to owe its existence to an east and west fault line, like that recorded by Dantz[5] in Speke's Gulf, while he attributes Jordans' Nullah and Smith's Sound on the south shore to others which have a meridional direction. Uhlig has recently[6] noted signs of another along the east coast near Shirati. North of the equator but little geological examination of the country has yet been attempted, but probably there also the differential movements of the ground have mainly determined the present drainage. Though it cannot be stated with any certainty till a more complete

1 The Nile in 1904, London, 1905, p. 21.
2 Report on the Upper Nile, p. 38.
3 "Mit Emin Pascha ins Herz von Afrika" ch. XXX.
4 See p. 43.
5 "Mitt. aus den deutschen Schutzgebieten," XVI., 1903, map 2.
6 Pet. Mitt., 1904, p. 226.

knowledge of the geology of the area is attained, there seem to be several directions of faulting which may be distinguished; the NNE. to SSW. faulting of the western plateau has already been mentioned, while in the north of the lake there seems to be also another series NW. to SE; thirdly there is the E. to W. series which Dantz has recorded south-west of the lake, near Nassa in the south-east, as defining Speke Gulf, and probably Kavirondo Bay in the north-east.

So little has been done to elucidate the geological structure of Uganda, that it would be rash to attempt any detailed account of its development. The most striking feature is the proximity of the watershed to the lake, only 10 to 15 kilometres usually separating from the lake shores the headwaters of the streams which flow northwards to the Victoria Nile below lake Choga. This certainly suggests the upheaval of a block along an approximately E.-W. axis, which cut off the drainage of the plateau lying to the south, and so formed the present lake in the low-lying area which lay between the more elevated areas east and west of it. The Nile leaving the lake at the Ripon Falls may mark a SSE. to NNW. fault line, lying, as it does, parallel to the numerous islands, and the general shore lines of the north-east corner of the lake. The present level of the falls seems to be maintained by a dyke of diorite rather than by a bed of hard rock, if we may judge from the depth of water, 12 metres, close to the upstream side of the falls, given in the sections taken in 1902;[1] also the photograph[1] taken in 1903 shows what looks very like the shoreward extension of this dyke in the foreground; the drop is 5 metres,[1] and below this the Nile falls rapidly in a series of rapids and small falls, till after a course of 65 kilometres it opens out into the stagnant waters of lake Choga.

Turning now to the south-western portion, Herrmann[2] has recently given an interesting account of the structure of the Kivu lake and the Rift valley at this point, which is instructive and throws light on some of the changes which this part of the country has undergone. From the north of Tanganika lake (about 780 metres) the valley rises gradually northwards to an altitude of 980 metres 30 kilometres south of lake Kivu; here a ridge of crystalline schists partially bars the valley, having been raised to an average height of 1800 metres above sea level, while the highest parts reach 2200 metres, and the mountain slopes which enclose the valley rise to over 3000 metres on the west and to 2,500 metres on the east. Lake Kivu itself lies at an altitude of 1,450 metres, and its surplus waters drain southwards by the Rusisi river

[1] Report on the Upper Nile, Plan I., b and Plate IV, p. 20.
[2] "Mitt. aus den deutschen Schutzgebieten," XVII, I., 1904.

which has cut its way through this ridge and falls down its southern face in a series of falls and rapids until in the more level country near Tanganika it becomes a placidly meandering river, which finally enters the lake by two mouths in a flat alluvial plain. To the north of Kivu lake lies the belt of volcanoes which have completely blocked the valley and cut off from lake Albert Edward the drainage which no doubt at one time reached it.

Thus a large block of the valley floor, which is bounded to the north and south by E.–W. fault lines, and on the east and west by the faults of the rift valley, has been raised; the northern fault is indicated by a dyke of coarse-grained pegmatite cutting into the mica schists which form the sides of the rift valley, and along this line the eight great volcanic cones have piled up their masses of lava beds and volcanic ash forcing the drainage of this part to find a way southwards through the ridges of the Kivu block. Before all this took place the Albert Edward lake may have been connected with that of Tanganika, while a similarly elevated block in the Semliki valley west of Ruwenzori maintained its waters at the higher level which its ancient beaches now mark.

Climate.—In this area, which is approximately enclosed by the 30th and 35th meridians and is to the north of lat. 4° S. meteorological stations are not numerous, nor do the series of observations extend over a long period of time, but the following stations furnish observations for temperature and sometimes humidity also :—

Names	Altitude	Latitude	Remarks
Entebbe[1]	1280 metres	0° 3′ S.	North shore.
Jinja[1]	1250 "	0° 27′ N.	" "
Mumias[1]	1440 "	0° 20′ N.	1 km. NE. of lake.
Mbarara[1]	1480 "	0° 39′ S.	In Ankole 130 km. west of [lake.
Masaka[1]	1250 "	0° 20′ S.	West of lake.
Bukoba[2]	1200 "	1° 20′ S.	South shore.
Muanza[2]	1200 "	2° 31′ S.	" "
Tabora[2]	1230 "	5° 3 S.	150 km. south of lake.

Rainfall is also measured at these stations, as well as at Nandi, Eldama Ravine and Shirati, on the east of lake Victoria, at Fort Portal in Toru, north-east of Ruwenzori and at Butiaba, on the east of the Albert lake.

The climate of the lake plateau is typically tropical, showing a very small yearly range of about 2° only, while the daily range of temper-

[1] Reports of Committee of British Association, 1891-1900, also Meteorological Office. Climatological observations I. Tropical Africa, London, 1904.
[2] Maurer. "Mitt. aus den deutsch. Schutzgebieten," 1903, XVI., I.

ature (non-periodic amplitude) is about 7° to 8°. From the elevated position of the plateau the mean annual temperature is about 21°–22°, and the mean daily maximum temperature is 26°, the corresponding minimum being 18° or 19°. For stations at a distance from the lake both the diurnal and annual ranges are greater, as is shown by Tabora. The humidity is high, as is natural at places near the equator, which during most of the year are within the rain and cloud belt. On or near the lake itself the humidity is high in the morning, and fairly high in the afternoon, Entebbe showing the highest value, having an average of 89% for the year at 7 a.m.; the afternoon observations taken at a few stations are of special interest as giving some idea of the amount of evaporation; the mean values for Entebbe 73%, Bukoba and Muanza 64% show that it is active on the lake itself while Tabora 52%, and a mean value of 65% for Mbarara for the months July-December indicate how large a proportion of the rain falling on the surface of the catchment basin is at once removed by evaporation. The only actual measurements of this climatic factor, so far as I am aware, are those made at Entebbe, February 24-27, 1903, by Mr. J.I. Craig, when the weather was close and damp, with fresh westerly breezes and occasional heavy rain;

24	February	3·8 mm.	Mean 3·4 mm. per diem.
25	"	3·0 "	
26	"	3·2 "	
27	"	3·5 "	

It is evident that this figure must be larger in the dry seasons, while over the country at a distance from the lake the average daily amount will probably reach 7 or 8 mm. a day.

MEAN TEMPERATURE. — (CENTIGRADE).

PLACE	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1. Entebbe	22·6	22·4	22·1	21·2	21·8	21·6	21·1	21·4	22·1	22·5	22·3	21·9	21·9
2. Jinja	21·2	..	..	22·7	22·3	22·6	20·9	21·6	22·2	21 9	22·1	21·8	[21·9]
3. Mumias	23·5	24·1	24·2	22·8	22·2	21·6	20·9	20·9	21·8	22·6	22·7	22·9	22·5
4. Mbarara	18·9	19·3	19·3	19·3	19·1	17·6	19·4	19·9	20·3	19·2	19·4	19·0	19·2
5. Bukoba	20·1	20·4	20·8	20·8	20·5	20·0	19·3	19·5	20·1	20·1	20·1	20·0	20·1
6. Muanza	21·5	21·6	22·2	21·5	21·5	21·9	22·1	21·8	22·5	22·2	21·7	21·1	21·8
7. Tabora	21·9	22·1	21·8	21·6	21·4	20·9	21·1	22·9	24·4	25·5	24·4	22·8	22·6

1. 1901 and 1902, 7 a.m., 2 p.m., 9 p.m. 2. 1902, 9 a.m. 3. 1901, 1902, January-August, 9 a.m. 4. 1902, 9 a.m. 5. 1893, 1894, 1895, 1897, 7 a.m., 2 p.m., 9 p.m. 6. April 1894-March 1895, 7 a.m., 2 p.m., 9 p.m. 7. 1894, 1895, 1899, 7. a.m., 2 p.m., 9 p.m.

For these last three stations, see Meteor. Beobachtungen aus Deutsch-Ostafrika. Mitt. aus den deutsch. Schutzgebieten, XVI. 1903.

Mean Daily Maximum Temperature. — (Centigrade).

Place	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Entebbe..	27·7	27·0	26·8	26·0	25·4	25·6	25·3	26·4	27·6	27·7	27·4	26·8	26·6
Jinja ..	29·4	28·4	27·8	27·7	27·9	27·6	26·6	27·7	28·9	29·1	28·9	27·0	28·1
Masaka ..	25·5	24·8	24·4	23·9	23·1	24·3	26·2	24·9	23·7	24·8	24·3	23·9	24·5
Mumias ..	29·1	..	28·2	26·4	24·4	..	..	..	..	..	..	..	..
Mbarara .	26·1	26·8	26·1	25·3	24·8	26·4	26·4	26·2	25·9	24·8	24·8	24·8	25·7
Bukoba ..	27·3	26·3	27·4	28·7	27·9	25·7	25·6	25·3	26·6	27·2	27·4	27·3	26·9
Muanza ..	26·9	26·1	28·5	26·9	26·7	..	27·7	27·5	26·7	28·5	22·7	25·8	[26·7]
Tabora ..	29·5	29·7	29·1	29·2	29·1	28·8	29·4	30·9	31·8	33·8	32·4	31·3	30·4

1. 1901, 1902 and 1904. 2. 1902 and 1904, except February and March 1902.

Mean Daily Minimum Temperature.[1] — (Centigrade).

Place	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Entebbe..	17·8	17·7	17·4	17·5	18·0	17·1	16·4	16·3	16·8	16·9	17·3	16·8	17·2
Jinja ..	..	..	..	18·1	17·1	16·9	16·0	15·9	16·4	16·7	17·4	16·7	[16·8]
Masaka ..	15·2	15·5	15·3	15·4	15·3	15·0	15·1	15·8	15·3	15·6	15·6	15·6	15·4
Mumias ..	13·8	15·4	14·6	16·3	14·8	14·0	13·4	14·9	13·9	14·3	13·5	15·3	14·5
Mbarara .	13·1	13·8	13·3	13·3	13·5	12·9	13·4	14·2	12·9	14·5	13·1	11·2	13·3
Bukoba ..	20·1	20·4	20·8	20·8	20·5	20·0	19·3	19·5	20·2	20·1	20·1	20·0	20·2
Muanza ..	17·6	19·1	..	17·3	17·8	..	16·3	17·4	18·4	17·5	18·0	17·8	[17·7]
Tabora ..	21·9	22·1	21·8	21·6	21·4	20·9	21·1	22·9	24·4	25·5	24·4	22·8	22·6

Mean Diurnal Range of Temperature. — (Maximum-Minimum).

Place	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Entebbe..	9·9	9·3	9·4	8·5	7·4	8·5	8·9	10·1	10·8	10·8	10·1	10·0	9·5
Jinja ..	..	..	..	9·6	10·8	10·7	10·6	11·8	12·3	12·4	11·5	10·3	[11·1]
Masaka ..	10·3	9·3	9·1	8·5	7·8	9·3	11·1	9·1	8·4	9·2	8·7	8·3	9·1
Mumias ..	15·3	..	13·6	10·1	9·6	..	..	..	..	..	..	..	..
Mbarara .	13·0	13·0	12·8	12·0	11·3	13·5	13·0	12·0	13·0	10·3	11·7	13·6	12·4
Bukoba ..	7·2	5·9	6·6	7·9	7·4	5·7	6·3	5·8	6·4	7·1	7·3	7·3	6·7
Muanza ..	9·3	7·0	..	9·6	8·9	..	11·4	10·1	8·3	11·0	4·7	8·0	[8·8]
Tabora ..	7·6	7·6	7·3	7·6	7·7	7·9	8·3	8·0	7·4	8·3	8·0	8·5	7·8

[1] Cf. also Pet. Mitt. 1905, articles by Dr. J. Hoffmann.

RELATIVE HUMIDITY. — (7 a.m. and 9 a.m.).

PLACE	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Entebbe ..	86	88	91	95	89	88	89	88	86	90	92	92	89
Jinga... ..	78	..	..	76	76	76	81	80	79	80	83	82	[79]
Msaka ..	..	..	..	..	..	..	98	97	..	98	98	98	..
Mumias ..	78	89	70	80	83	75	80	80	82	88	87	87	82
Mbarara ..	82	87	85	87	86	85	88	82	76	82	87	87	84
Bukoba ..	79	78	83	89	82	76	71	77	79	80	82	80	80
Muanza ..	80	77	79	81	78	76	65	67	75	72	75	81	76
Tabora ..	76	76	78	75	63	57	50	55	56	57	66	79	66

RELATIVE HUMIDITY. — (2 p.m.)

PLACE	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Entebbe ..	66	72	74	76	80	79	75	79	75	68	68	70	73
Mbarara ..	..	..	..	..	..	..	63	53	58	73	74	67	[65]
Bukoba ..	62	64	75	82	72	63	59	69	68	66	71	67	68
Muanza ..	68	60	70	69	66	68	56	54	63	63	64	70	64
Tabora ..	56	57	61	57	46	40	35	43	48	46	54	63	50

Rainfall.—The region of the lakes receives its rainfall from the equatorial cloud-belt which oscillates northwards and southwards of its mean position according to the declination of the sun; consequently rain falls in almost every month though at some stations south of the Victoria lake there is a dry season from June to September. At the present time there are a certain number of stations situated in the neighbourhood of the lakes at which rainfall observations are regularly made, but the majority of stations only provide data for the last few years, and longer series are rare; moreover many of the series are imperfect, many days and even months being wanting in consequence of the illness or absence of observers, or from other causes.

Throughout this vast area there is a wide difference between the rainfall of different districts, from the steppes on the east of the Victoria lake, where but little rain falls, and the streams only flow for two or three months in the year, to the valley of the Semliki river where, under the mountain mass of Ruwenzori, rain falls heavily and almost daily. The majority of the rainfall stations, which furnish observations, are grouped round the Victoria lake, and those which have been recently established in the neighbourhood of Ruwenzori and the Albert lake cannot yet furnish sufficient trustworthy data for

determining the average rainfall. Thus we are compelled to utilise largely the accounts of travellers who have passed through the different districts, though such observations, not being supported by exact measurement, are not easily comparable. As is usual in the equatorial zone most of the rain falls in heavy showers lasting for some hours, but continuous rain for 24 hours or more is less common. These falls of rain occur usually in the afternoons, the mornings and nights being mostly fine ; severe thunderstorms are very common, and in the rainy season they occur almost daily.

Commencing with the southern portion of the area, the German station of Tabora situated in lat. 5° 3′ S. and long. 32° 53′ E. furnishes a series of observations, which are of interest although the station is not within the Nile Basin. There are many gaps in the records but probably the average total rainfall amounts to about 650 mm. per annum, which falls from November to April, the remaining months being almost rainless, when the south-east trade wind sweeps over the district producing clear skies and dry atmospheric conditions.

On the southern shore of the Victoria lake at the German station of Muanza, on the Bukumbi gulf (lat. 2° 31′ S., long, 33° 5′ E.), rainfall observations have been taken in 1894-5, and again from October, 1901, to the present time. From these it would appear that the rainfall is considerable, probably 1500 mm. or more; the 12 months, April 1894–March 1895, gave a total of 1375 mm., while in 1902, 2834 mm. are recorded as having fallen, so that more observations are necessary before a trustworthy mean value can be arrived at. The mean values derived from the existing observations show two maxima in April-May and October-November, with a principal minimum in July.

A more extended series of observations is furnished by the German station of Bukoba on the west shore of the Victoria lake, rather to the south of the mouth of the Kagera river, in lat. 0° 56′ S. and long. 31° 46′ E. From the following table it will be seen that the mean total of rainfall for the year derived from the observations is 2146 mm., while the two maxima in April-May and November, as well as the minimum in July, are clearly marked.

On the north shore of the lake a long and most valuable series of observations is available from Uganda, Mackay, of the Church Missionary Society, having recorded the rainfall regularly from 1878 to 1886 at Natete, near Mengo. In 1893 observations were made at Namirembo, and also in 1896, 1897 and from 1900 to the present time at Entebbe. This last station is on the shore of the lake ; Namirembo and Natete are close together about 25 kilometres further north.

From these observations we obtain a mean annual rainfall of 1197 mm. for 1878–86 at Natete, and of 1476 mm. for Entebbe, or generally an average annual rainfall of about 1300 mm. for this part of the north shore of the lake. The two maxima occur in April and November with a minimum in July as at the other stations on the lake. Some rainfall observations are also available from Kavirondo gulf on the north-eastern shore of the lake where the rainfall was recorded from January to June, 1899, at Port Victoria, and from September, 1899, to the present time at Port Florence (Kisumu). These observations show an average annual rainfall of about 1250 mm. agreeing with that at Entebbe but the maxima are not so well defined occurring from February to May, and in November and December; the July-August minimum is clearly marked.

Besides these six stations there are others recently established, which have as yet only accumulated observations for a few months. Shirati on the eastern shore of lake Victoria shows the same low rainfall as the steppes to the east of it, and for the short periods during which observations exist the mean annual rainfall is only 730 mm.

In the region lying between the Victoria lake on the east, and the Albert and Albert Edward lakes on the west, observations are few.

The rainfall observations from Fort Portal in the Toru district, Masaka in the Buddu district, and Mbarara in the Ankole district, have not been long enough continued to furnish reliable mean values, as may be seen from the large variation in the amount recorded for the same month in different years, still the total yearly rainfall does not probably differ much from 1500 mm. while May and November are the wettest and June the driest of the months. Fort Portal has a higher rainfall than the other two on account of its proximity to the Ruwenzori range. Recently also at Butiaba, on the eastern shore of the Albert lake, the rainfall has been measured, reaching for 1904 the very moderate total of 700 mm., though there is no reason to believe this to have been an abnormally dry year in Central Africa.

Further south in Usiba[1] Herrmann states that the climate is unusually wet, and that it rains almost daily throughout the year; thunderstorms are frequent.

In Karagwe there appears to be heavy rain in March-April. In western Karagwe[2] Stuhlmann, at the beginning of April, describes heavy dew each morning, soaking all clothes, etc., then fine weather

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[1] "Der Wasiba und ihr Land," p. 44. R. Fitzner. "Der Kagera Nil," p. 40.
[2] "Mit Emin Pascha in Afrika," p. 237.

in the forenoon, but by noon cloud masses have formed, and in the afternoon there are heavy downpours accompanied by thunderstorms. Just before sunset the sky clears.

In Ruanda[1] von Götzen states that there are no defined wet and dry seasons, while in north Ruanda the natives, according to Langheld,[2] state that it rains throughout the year.

Dr. H. Maurer,[3] in discussing the observations of Bukoba and Muanza, points out that the effect of the great water surface of the Victoria lake, 68,000 square kilometres, is frequently sufficient to mask completely the seasonal winds; land and lake breezes blow with sufficient strength to obliterate the south-east trade winds here. Throughout the year at Bukoba at 2 p.m. the wind blows off the lake from ESE. and S., while at 9 p.m. a W. or NW. wind is blowing from the land. At Muanza at 7 a.m. a SE. wind is blowing towards the lake, but at 2 p.m. this is reversed and the NW. and N. wind completely overpower the SE. trade wind except in June and July. It is probably this predominance of easterly winds blowing off the lake that causes the high annual rainfall at Bukoba.

The mean monthly rainfall at different points of the lake plateau falling within the Nile basin is given in the following table, derived from observations up to the end of 1904.

Mean Monthly Rainfall. — (In Millimetres).

Place	Latitude	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Butiaba ..	—	29	6	131	**137**	99	123	29	158	37	130	96	90	965
Fort Portal.	0° 40′ N.	55	41	137	**168**	160	123	106	115	166	219	143	49	1482
Mbarara ..	0° 39′ S.	89	81	**179**	93	92	46	31	26	182	215	226	133	1493
Masaka. ..	0° 20′ S.	71	127	109	**234**	160	17	26	162	151	154	128	118	1358
Jinja	0° 27 N.	89	66	96	**210**	117	79	43	21	62	94	103	97	1177
Entebbe ..	0° 3′ S.	80	97	174	**233**	167	123	61	70	80	78	169	144	1476
Natete.. ..	0° 10′ N.	60	110	114	**187**	122	72	85	173	99	**133**	92	42	1189
Mumias. ..	0° 20′ S.	75	99	129	**239**	206	208	173	46	186	146	143	94	1844
Kisumu ..	0° 6′ S.	70	118	106	**162**	127	80	42	50	75	97	142	152	1216
Shirati[4] ..	1° 2′ S.	**91**	49	60	**169**	89	42	22	6	26	76	34	66	730
Bukoba[4] ..	1° 20′ S.	96	172	280	**571**	403	54	28	56	62	93	**208**	122	2146
Muanza[4] ..	2° 31′ S.	128	117	112	**184**	146	108	8	101	96	192	**237**	92	1521
Tabora[4] ..	5° 3′ S.	111	104	104	87	20	5	0	0	9	15	85	**122**	662

[1] "Durch Afrika von Ost nach West," Berlin 1895, p. 105.
[2] Ibid, p. 73.
[3] Zur Klimatologie von deutsch Ost Afrika, Archives, Der deutscher Seewarte, XXIV, 1901, p. 22.
[4] To end of 1903.

But for comparing one year with another, and especially one of the rainy seasons with its amount in different years, the stations near the Victoria lake are probably misleading on account of the influence of this water surface, so that the stations on the plateau to the east are preferable. As the rainfall of March, April and May is due to the passage of the rainbelt when it is on its yearly move northwards, followed by the southerly winds, the variations of rainfall of that season are of importance, since the further extension of these rains northward supplies in June, July, August and September the rainfall on the Sudan plains, and on the Abyssinian table-land—the catchment basin which supplies the Nile flood. Whether an unusual development of the rainfall in this equatorial belt is due to a westerly diversion of the moisture-bearing currents at the expense of the Abyssinian rainfall is a question which cannot yet be answered; certainly in some years heavy rainfall south of lat. 6° N. occurred in years when Abyssinian rainfall was markedly deficient, as in 1902, while it has also been deficient in years of bad Nile flood, as in 1899. The matter is an important one and the effect of local conditions in north-east Africa on the southerly monsun winds of the summer will not be fully understood till the part played by these equatorial rains is better known.[1]

The amount of rain recorded as falling in each month for the different years during which observations have been made are given in the tables which follow, but it is difficult to trace any definite relation between these amounts and the variation of the lake level for the reason given above. The rain-gauge stations are few and large areas of the country have none, while on the lake shores, where the local conditions prevent the rainfall being representative of the basin, nine out of thirteen stations are situated.

RAINFALL IN MILLIMETRES.

Tabora Latitude 5° 3′ S. Longitude 32° 53′ E. Altitude 1230 Metres.

Date	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1893	..	..	..	..	58	0	0	0	48	0	57	118	[281]
1894	167	77	208	165	1	34	0	0	0	2	95	83	832
1895	143	175	108	124	10	0	0	0	..	..	..	..	[560]
1899	101	125	110	45	0	0	0	..	0	13	71	..	[465]
1901	..	..	62	82	2	0	0	0	0	0	26	34	[206]
1902	50	57	57	46	2	2	0	0	4	2	43	89	352
1903	95	86	79	60	71	0	0	0	0	70	217	284	962
1904	132	119	210	36	13	0	0	0	0	16	51	168	745
Mean..	115	106	119	80	20	4	0	0	7	15	80	129	675

[1] See chap. X.

Muanza. LATITUDE 2° 31′ S. LONGITUDE 33° 5′ E. ALTITUDE 1135 METRES.

DATE	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	YEAR
1894	..	..	..	165	135	79	9	80	74	181	103	121	} 1375
1895	90	122	216	..	..	..	..	..	..	..	..	..	
1901	..	..	..	..	..	..	..	..	..	42	151	66	[259]
1902	92	43	72	217	378	357	10	226	276	470	602	92	2835
1903	202	187	..	..	..	..	..	..	..	..	..	..	[389]
Mean [1].	128	117	112	184	146	108	8	101	96	192	237	92	1521

Bukoba. LATITUDE 1° 20′ S. LONGITUDE 31° 52′ E. ALTITUDE 1140 METRES.

DATE	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	YEAR
1893	..	..	..	..	..	..	..	58	70	86	199	142	[555]
1894	56	..	..	..	320	12	27	60	5	110	195	74	[859]
1895	89	166	299	751	720	4	14	51	56	74	329	113	2666
1896	112	..	..	..	..	..	..	..	..	..	..	..	[112]
1897	..	..	..	391	168	146	43	57	118	101	147	195	[1366]
1898	130	126	228	..	..	..	..	..	..	..	..	..	[484]
1901	..	..	..	..	..	..	..	..	..	..	174	88	[262]
1902	70	224	312	..	..	..	..	..	..	..	..	..	[606]
1903	117	..	..	..	..	..	..	..	..	..	..	..	[117]
Mean [2].	96	172	280	571	403	54	28	56	62	93	209	122	2146

Shirati. LONGITUDE 33° 50′ E. LATITUDE 1° 2′ S. ALTITUDE 1135 METRES.

DATE	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	YEAR
Mean [3].	91	49	60	169	89	42	22	6	26	76	34	66	730

[1] Mean derived from April 1894–May 1895 and Oct. 1901-Dec. 1903. Uhlig in Deutsch Ost Afrika Zeitung 16 April 1904.

[2] Mean after Uhlig loc. cit.

[3] Mean for Nov. 1902–Dec. 1903. Uhlig loc. cit.

Natete. LATITUDE 0° 10′ N. LONGITUDE 32° 26′ E. ALTITUDE 1250 metres.

DATE	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	YEAR
1877	..	..	..	..	..	..	..	some	much	much	much	less	..
1878	..	..	..	132	38	38	..	..	..	..	54	89	[351]
1879	142	93	134	144	203	52	9	29	141	89	84	39	1159
1880	5	160	137	..	..	..	..	..	..	..	..	..	[302]
1881	85	123	168	345	108	66	67	88	77	90	119	60	1396
1882	40	126	54	214	98	48	74	79	119	193	71	26	1142
1883	112	66	75	180	110	75	136	120	71	57	100	20	1122
1884	13	84	76	110	62	99	91	36	110	235	110	8	1034
1885	30	128	168	145	140	132	133	87	78	135	108	52	1336
1886	52	98	98	226	221	64	..	..	..	..	..	..	[759]
Mean..	60	110	114	187	122	72	85	73	99	133	92	42	1189

Namirembo. (NEAR NATETE).

DATE	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	YEAR
1892	Heavy rain			..	..	..	..	..	..	..	..	..	..
1893	..	..	[74]	227	100	61	26	17	126	121	69	54	[875]
1894	9	..	..	..	..	..	..	..	..	..	..	..	[9]

Entebbe. LATITUDE 0° 3′ S. LONGITUDE 32° 30′ E. ALTITUDE 1160 metres.

DATE	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	YEAR
1896	..	..	..	217	113	81	8	104	60	117	306	119	[1125]
1897	44	64	100	349	267	81	73	..	..	..	..	..	[978]
1899	..	..	..	..	..	..	..	..	..	..	..	42	[42]
1900	60	108	154	345	68	148	11	74	87	39	152	318	1564
1901	94	125	133	199	199	128	102	5	17	49	58	105	1214
1902	74	177	73	129	105	28	57	101	142	114	197	96	1293
1903	167	18	335	221	175	260	133	30	113	83	95	139	1769
1904	42	91	250	172	242	137	46	106	59	66	203	186	1600
1905	55	18	239	138	209	169	144	44	108	165	194	187	1670
Mean..	77	86	183	221	172	129	72	66	84	90	172	149	1501

Bugala (Sesse Islands). LAT. 0° 10′ S. LONG. 32° 20′ E. ALT. 1135 metres.

DATE	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	YEAR
1904	..	..	..	245	428	72	..	110	89	142	323	246	[1655]
1905	143	93	255	208	332	117	135	<		not received		>	[1283]
Mean..	143	93	255	226	380	94	135	110	89	142	323	246	2236

Jinja. LAT. 0° 27′ N. LONG. 32° 12′ E. ALT. 1135 metres.

DATE	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	YEAR
1902	76	103	28	279	174	24	77	190	18	87	119	103	1278
1903	145	48	115	< 300 >		152	< 83 >		96	127	43	58	1167
1904	48	47	145	151	77	62	22	125	73	88	147	131	1116
1905	62	18	98	100	104	12	87	69	77	137	231	76	1071
Mean..	83	54	96	170	126	62	58	106	66	110	135	92	1157

Kisumu. LAT. 0° 6′ S. LONG. 34° 36′ E. ALT. 1135 metres.

DATE	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	YEAR
1899	* 3	* 3	26	86	123	65	2	..	68	74	118	128	[690]
1900	132	163	118	128	47	75	39	68	93	73	159	158	1253
1901	54	229	194	272	98	53	49	9	17	116	104	78	1273
1902	21	34	45	..	..	39	90	32	104	75	310	187	[937]
1903	145	131	158	202	220	232	27	20	96	153	18	112	1514
1904	0	36	96	122	146	17	43	118	43	91	144	249	1105
1905	129	73	234	100	51	42	64	56	58	43	163	350	1363
Mean..	80	111	124	152	114	75	45	50	68	89	145	180	1238

* Days.

Mumia's. LAT. 0° 20′ N. LONG. 34° 30′ E. ALT. 1220 metres.

DATE	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	YEAR
1897	90	112	151	226	147	321	157	273	406	277	178	34	2372
1898	68	55	89	302	203	291	211	117	119	105	177	17	1754
1899	..	..	40	295	223	122	66	64	91	102	61	71	[1135]
1900	111	216	174	109	179	125	103	152	123	116	247	216	1871
1901	26	144	110	292	228	58	124	77	174	118	85	45	1481
1902	38	22	70	213	299	113	282	196	177	158	187	138	1893
1903	176	75	243	199	198	410	262	85	274	169	114	114	2319
1904	18	66	152	279	172	221	175	203	126	126	96	114	1748
1905	106	58	128	154	232	89	127	247	84	196	246	226	1893
Mean ..	79	94	129	230	209	194	167	157	175	152	155	108	1849

History levels
Lake Victoria p 35f - 47

Lake Ed. Albert p 67-8

Lake Albert p 74 - 77

Trace Khartoum curve on graph paper 1869-83

Compute mean max vol.
Sep 1
2
3

Khartoum mean 1912-27

Plot Aswan max vol no.
Khartoum gauge max

In the summer months, when the rain-belt lies to the. northward, these dry south and south-east winds must blow across the lake catchment basin even though the diurnal reversal of winds on the lake itself is not mastered by them, and will greatly increase the evaporation. It will be seen, when the lake-gauge readings are examined, that this is actually the case, and that there is a very marked diminution of the water during the greater dry season, which must be due primarily to greatly increased evaporation from the lake surface, and in a much lesser degree to the discharge at the Ripon falls which when it reaches 600 cubic metres per second is only equivalent to 0.76 mm. from the whole lake surface daily.

PERCENTAGE FREQUENCY OF WINDS ON LAKE VICTORIA.

Tabora.—1893-1899 (Observations at 7 a.m., 2 p.m., 9 p.m.)

Months	N	NE	E	SE	S	SW	W	NW	Calm
January ..	6	12	17	12	3	3	7	4	36
February ..	4	9	17	9	12	7	7	6	29
March.. ..	8	13	28	7	1	4	3	4	32
April	1	9	49	15	0	2	1	1	22
May	0	5	51	22	1	1	0	0	20
June	0	3	46	25	8	3	0	1	14
July	0	2	65	19	4	1	0	0	9
August.. ..	0	3	68	20	2	1	0	0	6
September ..	0	7	54	19	1	0	0	1	18
October. ..	1	8	46	22	4	2	1	1	15
November ..	2	13	40	7	3	2	3	2	28
December ..	3	11	21	2	1	6	16	3	37

Muanza.—April 1894-March 1895 (Observations 7 a.m., 2 p.m., 9 p.m.)

Months	N	NE	E	SE	S	SW	W	NW	Calm
January ..	30	7	12	15	10	7	10	7	2
February ..	41	7	16	16	8	4	0	15	3
March.. ..	4	18	4	17	2	4	5	34	12
April	12	7	5	18	11	9	1	13	24
May	5	8	2	30	8	1	5	20	21
June	9	12	10	30	12	5	3	3	16
July	26	4	6	13	32	9	1	4	5
August.. ..	31	13	10	11	16	6	0	8	5
September ..	44	8	14	12	1	0	3	18	0
October. ..	19	5	3	23	0	2	0	36	12
November ..	16	19	13	6	5	13	11	11	6
December ..	30	6	13	24	2	4	6	12	3

Bukoba.[1]—(Observations 7 a.m., 2 p.m., 9 p.m.)

Months	N	NE	E	SE	S	SW	W	NW	Calm
January ..	9	2	3	21	9	2	2	19	33
February ..	11	2	14	11	11	6	16	16	13
March.. ..	8	8	12	14	7	9	18	14	10
April	7	0	17	18	7	11	21	11	9
May	4	0	2	28	16	2	4	2	41
June	2	0	6	17	21	11	5	4	33
July	3	0	6	26	17	3	6	9	31
August . ..	7	1	4	23	15	1	7	19	24
September ..	10	1	9	16	7	1	5	22	28
October ..	15	2	4	20	6	2	14	14	25
November ..	19	2	6	18	6	2	7	20	19
December ..	11	4	7	19	5	1	3	27	23

Entebbe[2].—July 1901-December 1903.

Months	N	NE	E	SE	S	SW	W	NW	Calm
January ..	6	0	0	11	16	1	5	3	58
February ..	3	0	1	8	28	2	4	2	52
March.. ..	2	0	1	7	26	7	7	1	49
April	2	1	16	7	16	3	2	1	52
May	2	0	9	5	17	3	0	0	64
June	1	1	1	12	14	2	3	3	63
July	5	0	1	9	22	1	2	2	58
August . ..	2	2	3	9	20	1	2	2	59
September ..	5	6	0	15	16	2	4	1	52
October. ..	3	1	1	12	17	4	3	3	56
November ..	2	1	1	12	12	1	5	2	64
December ..	0	1	1	11	12	2	8	1	64

Variations in lake level. [3]—The variations in the level of the Victoria lake as of other lakes admit of division into several distinct classes :—

a) The increase or decrease in size, due to climatic or other changes, which affect them over long periods;

b) The oscillations due to variations in meteorological conditions having a comparatively short period, such as that of about 35 years, detected by Brückner,[4] and in which a period of high levels is followed by a period of lower levels;

c) The annual oscillations due, in the case of the Victoria lake, to the April and November rains.

1 Maurer loc. cit.
2 Meteorological Office, London.
3 From Appendix III of a Report on the Basin of the Upper Nile, Cairo, 1904.
4 "Klimaschwankungen." Vienna, 1890.

d) The alternation of lake and land breezes causes a daily oscillation of the water, which is more noticeable in large landlocked gulfs like Kavirondo (Kisumu) than in more open situations as at Entebbe.

e) Minor irregular changes (Seiches) which can only be briefly mentioned, since the evidence available is quite insufficient for any discussion of them.

For the first type, there is much evidence all round the lake that in early times its waters stood at a higher level. Scott Elliot[1] attributes the flat alluvial plains which fill the valleys above the present lake level, to the detritus brought down by the tributary streams and deposited in the still waters of the lake. He puts the upper limit of these alluvial tracts at 30 metres above the present lake level, and notes that the lake apparently remained stationary for a considerable time about 13 metres above its present level.

In any case, seeing at what a small elevation the water-parting on the north shore of the lake is situated, there can have been no very great vertical extension of the lake since the earth movements which turned the drainage of this part towards the Victoria Nile.

Secondly we come to the periodical variation of the lake for which the evidence is furnished by observations made by travellers and others visiting or residing by the lake, and by the series of the lake gauge-readings taken at three points on the northern shore of the lake since 1896. The French missionaries at Bukumbi on Smith's Sound (south shore) are said to have possessed a record of the level of the lake extending over many years, but it is reported to have been lost with much other scientific material by the sinking of a canoe on the lake.

In discussing the changes in the lake level during a series of years from the observations of travellers there is usually some doubt as to the exact nature of the rise or fall they record. In the case of the Victoria lake, where the average annual range during the years 1896-1904 is $0^{m}\cdot660$, it is often uncertain, when a rise of 3 feet is recorded, whether this is a somewhat larger range than usual, or whether a real increase of the mean level of the lake is intended. In the years for which gauge-readings exist the range of the lake has varied from $0^{m}\cdot46$ to $0^{m}\cdot89$, and variations in range may be indicated to travellers as signs of rising or falling lake level though they may be of a temporary character only; caution is therefore necessary in interpreting isolated observations.

1 A Naturalist in Mid-Africa. London, 1896, p. 39.

To take the first class of observations:—

In March, 1875 Stanley[1] described the island of Ukerewé as separated from the mainland by a narrow channel, at one place only 6 feet wide and 3 feet deep; in June of the same year he punted through it.[2]

Wilson[3] notes that in February, 1877 there was exceptionally heavy rain to the south of the lake (Uyui), and attributes to this an unusual rise of the lake at the time amounting to 2 feet.

Hutchinson[4] states that Wilson noticed soon after his arrival at Kagehi (south shore), in the middle of February 1877, that the lake was slowly rising. By May, 10 days after the rains had ceased, the level was at its maximum, and then began to recede; the total rise from a point marked on a rock in February was 2 feet. On his arrival again at Kagehi on the 12th January, 1878, he found that the water level was within 1 to 1½ inches of the maximum as marked on the rock in the previous May, showing that the November-December rains had been particularly heavy. On revisiting Kagehi on the 15th March 1878, the level was the same as on the 12th January. A few days later at Uganda he obtained evidence of the unusually high level of the lake there also.

Felkin[5] records that the lake rose 3 feet above its usual June maximum in August and September, 1878, in consequence of the exceptionally heavy rains.

Fischer[6] records a failure of rain to the north-east of the lake near Kisumu in the early part of 1886, and says that two years previously the rain had failed, so by this time the fall of the lake seems to have set in.

Stanley, on his second visit to the lake, after the rescue of Emin Pasha, states[7] that by September, 1889 the French missionaries at Bukumbi had determined by observation that the lake had fallen 3 feet in the previous 11 years. Here again there is some ambiguity; a fall of the annual mean level should be meant, but perhaps the maxima of different years are referred to. He was also told[7] that Ukerewé was no longer an island.

In April, 1891, Dermott[8] noted on the island of Kitaro, south of Ukerewé, that the lake was at a level 5 or 6 feet lower than the high-

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[1] "Through the Dark Continent," I., p. 160.
[2] Ibid. p 257.
[3] Proc. Roy. Geog. Soc., 1880, p. 616.
[4] Ibid. 1879, p. 136.
[5] "Uganda and the Sudan," I., p. 396.
[6] Pet. Mitt., 1895, p. 67.
[7] "In Darkest Africa," II., p. 396.
[8] Proc. Roy. Geog. Soc., 1892, p. 120.

level marks on the rocks; he also states that the Lugeshi (Rugezi) straits between Ukerewé and the mainland were not passable, there being only a few inches of water; as in April the lake is usually rising steadily, this observation tends to bear out Stanley's information, and points to the lake having been especially low in 1889-91.

Lugard[1] in June, 1892, records an exceptionally heavy rainfall and a marked rise in the lake, "some 6 feet perhaps above its ordinary level." This was due to heavy rainfall between the November and February preceding.

Baumann[2] in 1892 finds Ukerewé to be an island, but the Rugezi strait is fordable, and it is shown as an island in the latest maps: thus there had been a rise of the lake due to the 1891 rains after Dermott's visit.

Baumann[2] collected all information on the subject that he could, and was of opinion that the lake level fell from 1880 more than a metre, but at the time of his visit, (1892-3) it was rising. This was not the commencement of a period of maxima, as seems to be implied, but was due to the heavy rains of November, 1891, to February, 1892, which caused a higher mean lake level in 1892.

Père Brard[3] states that the lake level on the southern coast rose, in 1895, 1·5 metres in consequence of the heavy rains, and plantations for 200 metres along the southern shores were destroyed. The natives said that no such high level had occurred for 30 years, but that of 1878 was certainly as high or higher. In this case a high maximum is probably meant as the heavy rains began in March, and were unusually heavy at both Muanza and Bukoba throughout April and May.

From the information collected by Sir W. Garstin in January, 1903, we have:—

a) Père Bresson, of the French Mission at Entebbe, states that there has been a considerable fall in the lake level near Kisibu (between Entebbe and the Murchison Gulf).

b) The natives say that there has been a considerable fall.

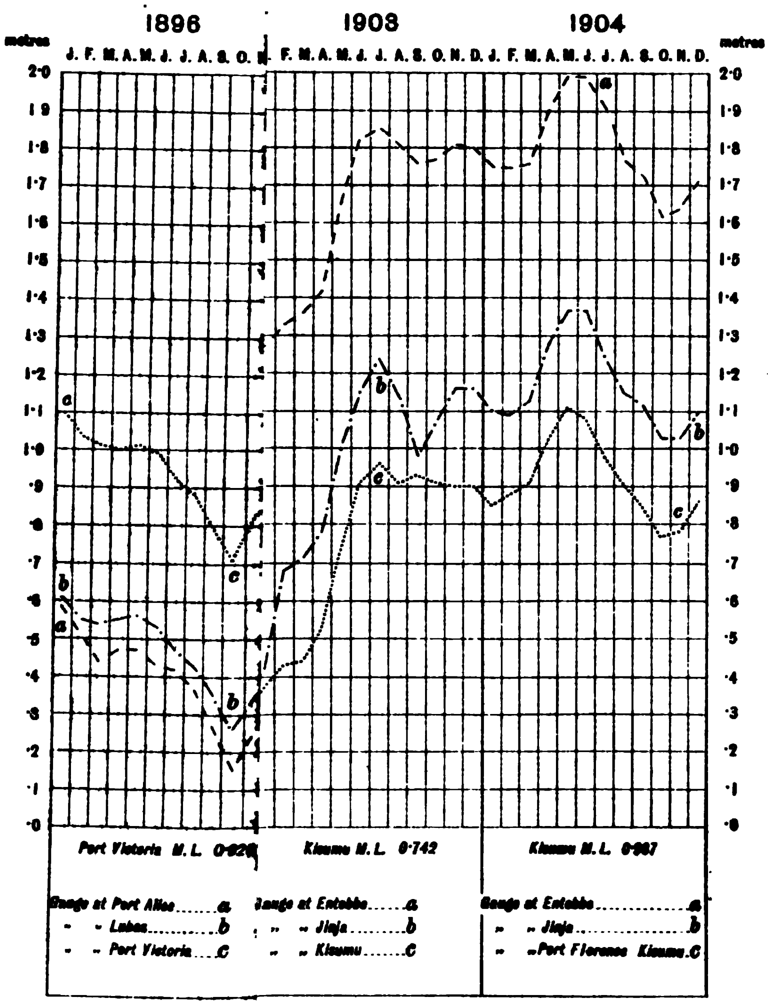
c) Mr. Pordage states that the reef in front of Entebbe was covered in 1896, but in February, 1903, it was well out of water. The mean level of the lake has fallen about 0·6 metres between these dates, according to the gauge readings (see Plate V).

d) According to Mr. Wilson since 1894, 3 feet has been the maximum rise of the lake, and that was in 1895.

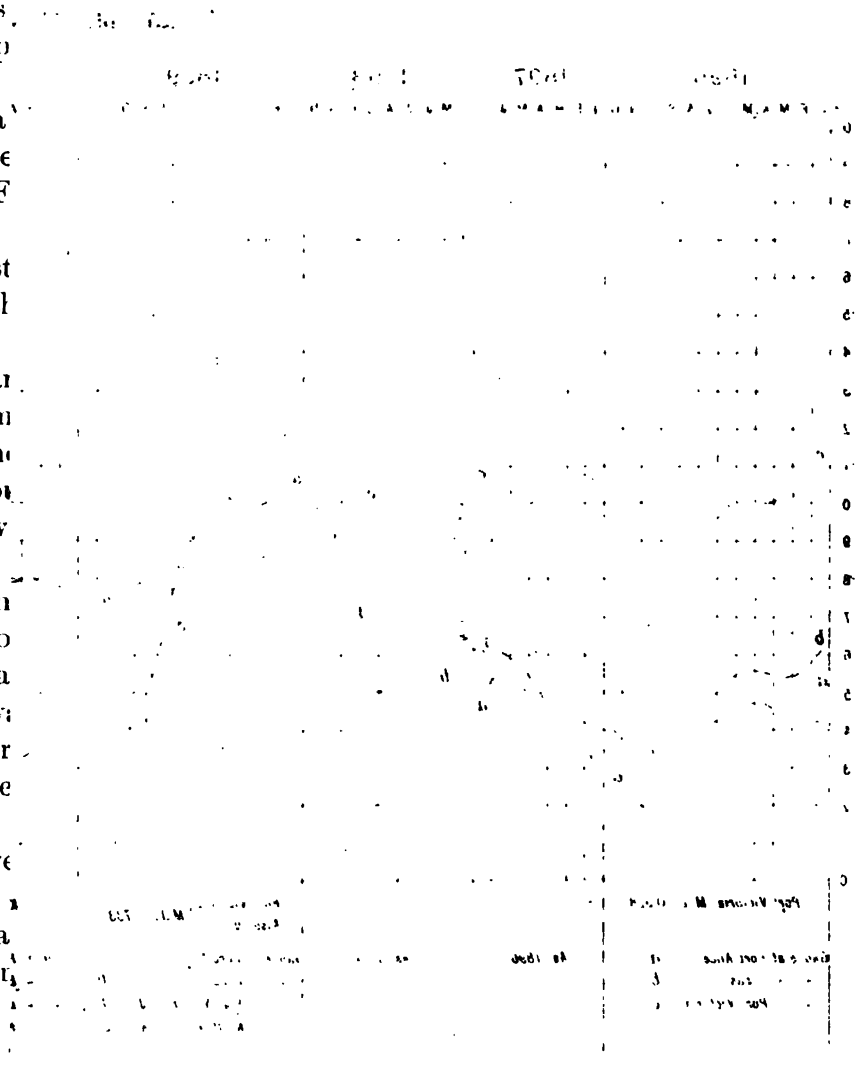
e) Mr. Martin says that since 1889, when he first visited the lake,

[1] Ibid. 1892, p. 827.
[2] Durch Masai-land zur Nilquelle, p. 143.
[3] Pet. Mitt. 1897, p. 77.

PLATE IV.



Survey Department.



there has been a distinct fall, and certainly 4 to 5 feet since 1896. At Kisumu there are villages and pasture where in 1889 there was water. He thinks it has fallen 4 to 6 feet. At the ford above the Ripon Falls the water extended horizontally 30 feet more than at present.

Sesse Islands show shallowing channels, and what were formerly separate islands are now connected to the neighbouring land.

From Plate IV it will be seen that in the early part of 1903 the lake was as low as it had been since gauge readings began.

Besides these evidences there exists a tradition of a periodical rise and fall of the lake extending over from 25 to 30 years.

Stuhlmann[1] speaks of meeting near Muanza a native some 60 or 70 years old who stated that he was then able to work again the banana plantation which his father had, but which had been abandoned in the speaker's boyhood on account of the rising of the lake level.

Gedge[2] states that according to natives on the north of the lake there is a periodical rise and fall, having a period of about 25 years; at the time of writing, apparently, in 1891, the level was between 8 and 9 feet below the highest water mark, and they pointed out plantations which were at the time cultivated, and which would be again flooded.

Though these various testimonies are not quite concordant, there appears to be, as Stuhlmann also says,[3] a general agreement on the part of Europeans and natives that the lake level has sunk recently, and particularly from 1878 to 1892, after which according to Baumann, there was a tendency to rise. This rise, however, appears to have been limited to the years 1892-1895, or perhaps even to 1892 and 1895 only, which were years of heavy rainfall. From this time the fall has been almost continuous up to the end of 1902, as the lake gauges show.

These data may be tabulated as follows:—

1878	Very high in August and September.
1884	Drought NE. of lake. ?
1886	Drought NE. of lake.
1878 1890	General fall recorded on southern shore.
1891	Low.
1892	Very high, heavy rainfall, tendency to rise.
1895	Very high.

Comparing these with the fairly complete series of rainfall observations at Natete near Entebbe, 1884 and 1886 were not there very deficient in rainfall; 1884 had a total of 1034 millimetres against a

[1] Mitt. aus den deutsch. Schutzgebieten. V., p. 190, 1892.
[2] Proc. Roy. Geog. Soc., 1892, p. 323.
[3] "Mit Emin Pascha ins Herz von Afrika," p. 729.

mean for 8 years of 1189, and the early months of 1886 were up to the average. But the eastern shore throughout is much drier, and it is certain that all over the lake basin large variations in rainfall may occur within short distances.

Sieger,[1] after reviewing the evidence for the variations in level of the Central African lakes, sums up his results as in the following table:—

Movement.	Period.	Lake.
Minimum	18th Century	Chad and Tanganika
Low	1840-1850	" "
Rapid rise	1853-1855	Chad
Fall	Before 1866	Chad
Rapid rise	1875-76 or 1878	Chad, Nyassa, Tanganika
Fall	1879-to 1886	Nyassa, Tanganika, Kilwa.

Generally speaking then 1850 to 1878 would seem to have been a wet period, and 1879 to 1886 a dry one for the whole of Central Africa; but from what the gauge readings on lake Victoria teach (see Plates IV, V and VI) it is clear that lakes where evaporation is the main controlling factor, and the volume discharged from the lake is comparatively small, very considerable variation in the level may take place without any marked increase in the average rainfall since the lake level responds quickly to any temporary increase in loss or supply.

Turning now to the recorded readings of the lake level, there are three lake gauges on the Victoria lake, all situated on the northern or north-east shore of the lake; in German territory one has been established but the site is not yet known. Of these one is at Entebbe on the north shore of the lake, the second at Jinja, just above the Ripon Falls, where the Nile leaves the lake, and the third is at Kisumu, near the railway terminus on the north-east shore of the lake and at the head of the almost land-locked Kavirondo Gulf.

All these gauges have been moved since the daily readings of the lake level were first commenced in 1896, and some considerable gaps occur in the records, still, after eliminating as far as possible these sources of error, there remains a valuable collection of data from which it is possible to obtain a considerable amount of information. The gauges were first fixed at the end of 1895 by Mr. Macalister,[2] care being taken to have as firm a foundation as possible to avoid subsidence of the gauge; and observations were commenced January 1, 1896, at Port Alice, which is close to the present site of the Entebbe gauge, and at the Luba's gauge which was close to Fort Luba's on the east side of the

[1] Bericht f. d. XIII. Vereins-Jahr (1887) des Verein d. Geographen. a.d. Univ. Wien.
[2] Geog. Jour., Oct., 1901, p. 403.

Napoleon Gulf on the north shore of the lake, not far from the Ripon Falls. The third gauge in 1896 was at Port Victoria at the south-western end of Berkeley Bay, an inlet of moderate size on the north-east shore of the lake.

The three gauges at Port Alice, Luba's and Port Victoria were observed regularly until the end of July, 1897, when the Sudanese mutiny interrupted the observations. The readings of the Port Alice and Port Victoria gauges were resumed on September 1, 1898, and that at Luba's on May 1, 1898. During this interval there seems to have been no interference with these three gauges, but this is now of little importance since on the October 1, 1898, the three gauges were adjusted by Capt. C. N. Fowler.[1] On the September 30, 1898, the three gauges stood as follows:—

	feet.	in.
Port Alice	2	4
Luba's	1	7½
Port Victoria...	3	3

The lake level had been very steady all September, the range being 2½ inches or less.

It appears that Port Victoria was the gauge to which the others were adjusted, and Capt. C. N. Fowler in reply to a query on the subject writes as follows:—

"In year 1898 I was consulted by Mr. Ernest Berkeley, H. M. Commissioner, as to the fixing of a "zero" for all stations on the lake; the result of the consultation was as follows:—

"Having fixed a 'zero' at Entebbe (Port Alice), I proceeded in the steam launch *Victoria* at full speed to Luba's station, some 2½ hours' steaming, and adjusted the 'zero' at that station to a depth similar to that recorded on Entebbe gauge, no telegraph available. Weather calm during trip. Method primitive, but only one available."

It is seen from the daily observations that on the following day the three gauges were practically in agreement, the gauge scales of two having been depressed, so, though Captain Fowler does not definitely say so, Port Victoria was the gauge to which the other two were adjusted.

	Port Alice.	Luba's.	Port Victoria.
September 30...	2 ft. 4 in.	1 ft. 7½ in.	3 ft. 3 in.
Adjustment	+ 10 „	+1 „ 6 „	0 „ 0 „
October 1	3 ft. 2 „	3 „ 1½ „	3 „ 2½ „ [2]

[1] Brit. Assoc. Rep., 1901.
[2] 0·5 inch. fall.

After this the gauge remained at Port Alice until March 31, 1900, when it was removed and set up at Entebbe. These places are close together, and this change introduced no appreciable error into the series of observations, for the gauge at Port Alice had been reading 2 ft 8 in. from 19th to the 31st of March; it was erected at Entebbe on the 1st April to read 2 ft. 7 in., and the same reading was recorded for every day in April, so that the lake level was practically stationary during the move of the gauge, as is shown by the following readings of the other gauges:—

1900	Luba's ft. in.	Kisumu ft. in.
30th March	1 4.0	2 0.0
31st "	1 5.0	2 0.0
1st April	1 4.0	2 2.0
2nd "	1 3.5	2 2.0

Unfortunately this gauge was knocked down or washed away on May 31, 1901, and was not replaced until October 20 of the same year so that the fall of the lake at this site from the maximum is not recorded.

After Luba's gauge had been brought into accord with the other two by depressing its zero 1ft. 6 in., on October 1, 1898, it was regularly observed until July 31, 1901, and on August 1, 1901, the gauge was transferred to Jinja, close to the head of the Ripon Falls and about 16 kilometres north-west of Luba's. Here again no error has been introduced into the series of observations, for taking the daily readings at the time we have:

		ft. in.	Kisumu ft. in.
Luba's gauge ...	July 29, 1901 ...	2. 2	2. 6
	" 30 " ...	2. 2	2. 8
	" 31 " ...	2. 1	2. 6
Jinja gauge ...	Aug. 1 " ...	2. 1	2. 8
	" 2 " ...	2. 1	2. 8
	" 3 " ...	2. 1	2. 6

Thus we have in the Luba's-Jinja series of gauge-readings a practically continuous record from 1st October, 1898, to the present time.

This gauge was however altered in December, 1901, by having its zero depressed 11 inches.

	Jinja ft. in.	Entebbe ft. in.	Kisumu ft. in.
December 20, 1901 the gauge read	1. 3	3. 6	1. 3
" 21 " " " "	2. 1	3. 6	1. 3
Difference....	0. 10	0. 0	0. 0

The third gauge has had a more chequered career. After readings were resumed in September, 1898 at Port Victoria, they were continued

until July 31, 1899. This station was then closed, and the gauge was transferred to Port Ugowe (Port Florence) on August 23, 1899. This was a move from a comparatively open situation near the south end of Berkeley Bay to the head of the almost land-locked Kavirondo Gulf. The amount of correction which should be applied to all subsequent readings of the Kisumu gauge, in order to bring them into accordance with the Port Victoria readings, can be best deduced by a comparison of the readings with those of the Luba's gauge before and after August, 1899.

		ft.	in.
Port Victoria	July 29, 1899	2.	5½
	„ 30, „	2.	4½
	„ 31, „	2.	4
Port Ugowe	Aug. 23, „	2.	6
	„ 24, „	2.	6
	„ 25, „	2.	5

The lapse of time, viz, 23 days, is considerable, and during it we find, by reference to the other two gauges, that the Luba's gauge showed a fall of 10½ inches, and the Port Alice gauge a fall of 5 inches, but the latter gauge was not at that time furnishing a reliable record of the lake level, as will be shown later.

After the gauges had been adjusted on 1st October, 1898, the mean readings for that month, in centimetres, were (see page 47).

Port Victoria	Luba's	Difference
cm.	cm.	cm.
99	95	+4

In 1899 we have the following comparisons of the monthly means in centimetres :—

	Port Victoria	Luba's	Difference	
April	89	84	+ 5	Mean +3 cm.
January	99	94	+ 5	
June	99	93	+ 6	
July	82	86	− 4	
August 23-31 [1]	74	58	+16	+20 cm.
September	69	48	+21	
October	59	38	+21	
November	58	35	+23	

So that a deduction of 17 centimetres should be made from the monthly means of the lake level readings recorded on the Kisumu gauge from August 23, 1899, to bring them into agreement with those recorded before that date.

[1] From this date at Port Ugowe (Kisumu).

At the end of September, 1900, the gauge at Port Ugowe (Port Florence) was reading :—

1900	ft.	in.
September 29	1	11
„ 30	1	11
October 1	1	8
„ 2	1	7

but from the 1st October the readings were at Kisumu, and have continued to be so down to the present date.

Kisumu is a village on the Kavirondo Gulf, but the site of the gauge was not altered when the name of the gauge station was changed. For this third gauge therefore there is fairly continuous series of observations at Port Victoria and then at Port Ugowe, and as we have seen, a correction of 0·17 metre should be applied to all observations since August 23, 1899, to bring them into uniformity with the previous observations. The gauge now used is one at Port Florence near the railway terminus.

Having shortly detailed the various changes it remains to compare the readings of the three gauges. This is most conveniently done by plotting the monthly mean of the readings of each gauge (see Plate IV), and the result may be summarized as follows :—

Throughout 1896 and 1897 the curves of the three gauges, Port Alice, Port Victoria and Luba's keep parallel to each other.

On the September 30 and October 1, 1898, the gauges read :–

	Port Alice		Port Victoria		Luba's	
	ft.	in.	ft.	in.	ft.	in.
September 30	2	4	3	3	1	7½
October 1	3	2	3	2½	3	1½

being now practically in agreement. In December, however, the mean of the Port Alice gauge was 13 centimetres above that of Luba's and 8 centimetres above that of Port Victoria. The former difference remained fairly constant until August, when it rapidly increased to 29 centimetres and by January, 1900, it had reached 38 centimetres.

It is unfortunate that the time when this second increase of the difference appears (July-August, 1899) is when the Port Victoria gauge was moved to Port Ugowe, but as has already been shown above the deduction of 17 centimetres from the Ugowe-Kisumu readings reduces the monthly means to those of the Port Victoria readings, with a probable error of 1 or 2 centimetres only. Thus a continuous curve is obtainable with which the fluctuations of Port Alice (Entebbe)

gauge can be compared. These corrected values for Kisumu have been plotted and will be seen to follow the Jinja curve fairly closely from August, 1899, to November, 1901.

During this time the Entebbe gauge (up to the time it was destroyed in June, 1901) differed considerably from the other two, by about 35 centimetres from September, 1899, to October, 1900, and afterwards by a less amount up to February, 1901.

The most probable explanation of this is that the land at Entebbe was sinking slightly from about October, 1898, or indeed earlier, since the difference between mean monthly values of the Port Alice (Entebbe) gauge and Luba's gauge was 23 centimetres in September, 1898, although throughout 1896 and 1897 the difference was but 5 to 10 centimetres. In 1899 the sinking continued, being marked between August and October, but being on a falling gauge it did not attract attention. At the end of 1900 and the early months of 1901 a slight elevation seems to have occurred, while in May and probably June a renewed sinking took place but the destruction of the gauge renders proof impossible.

So far it appears that there was on the whole a downward movement of the land near Entebbe in 1898 and 1899, which did not affect either Napoleon Gulf or the north-east shore of the lake.

It appears more than probable that there was something abnormal at Entebbe in April-May, 1901, since a telegram was received at Cairo from Entebbe reporting a rise of 3 ft. 3 in. in the lake level in six months[1] though the other two gauges showed only about 2 feet rise.

Taking the monthly means from page 49 we have in centimetres:—

1901	Entebbe.	Kisumu.	Luba's.	Entebbe—Kisumu.	Entebbe—Luba's.
	cm.	cm.	cm.	cm.	cm.
January	58	32	35	26	23
February	61	37	36	24	25
March	77	43	48	34	29
April	116	68	66	48	50
May	153	95	89	58	64

At this point the gauge at Entebbe was destroyed. An additional proof that this rise recorded at Entebbe does not represent the rise of the lake is furnished by Commander B. Whitehouse, R. N., who,[2] denies that it was unusually high in May 1901, since he points out that in November, 1898, it was 16 ft. below a bench-mark at Port Florence;

[1] Report of Public Works Ministry, Cairo, 1901, p. 170.
[2] A Report on the Basin of the Upper Nile. Cairo, 1904. App. III, p. 35.

in January, 1900, the level was low, and 18 ft. 1 inch below the same mark; soundings on the entrance line to the harbour showed the same decrease in depth. By May, 1901, the level had risen to 3 ft. 4 in. on the gauge, bringing back the level to what it had been in November, 1898. Thus an unusually high lake level was recorded at Entebbe only. This time the local downward movement of the land occurred during the normal rise of the lake, and therefore attracted special attention, but the similar though larger movement in the autumn of 1899, was on a falling gauge and, as we have seen, was not observed.

These variations of the Entebbe gauge extend over several months, so that they cannot be explained by local wind action, and as the differences are those between the monthly means of different months, they would not be caused by occasional seiches.

Thus of the three gauges, that at Port Alice (Entebbe) records abnormal changes of the lake level, which are not borne out by the readings of the other gauges, so that any discussion of the annual oscillation of the lake must be based on one of the others.

The Port Victoria-Kisumu gauge, as has been related above, was the one to which the others were adjusted in October, 1898. After August, 1899, a correction of about 17 centimetres (see p. 41) has to be made to the readings, and they then follow the Jinja readings very closely during 1900 and 1901. In 1902 and 1903 there are months in which the parallelism between the Kisumu and Jinja gauges is not maintained, *e.g.*, the difference in June, 1902, is 30 cm., while in January, 1903, it is only 5 cm., but throughout this period the Kisumu curve keeps closely parallel to the Entebbe curve. Thus the Port Victoria-Kisumu series of lake readings furnish the most reliable series of the three gauges, and it will be better, therefore, to study the annual oscillations on this gauge, especially as Whitehouse's observations show that for two and a half years at least the gauge was certainly not interfered with.

These divergences in the curve of the Jinja gauge readings are curious, and perhaps if earth-movement is assumed in the case of Entebbe, the same argument should be applied to the Jinja gauge from the end of 1901 to 1903. It will be seen that the Jinja curve from November, 1901, to February, 1902, was on the whole rising, while those of Entebbe and Kisumu were falling steadily; again in December, 1902, Jinja was steady, while Entebbe and Kisumu were rising, and in February, 1903, the reverse was the case. Still it is not so marked as in the case of the Entebbe gauge from 1897-1901.

From plate IV it will be seen that the annual oscillation of the lake, level, so far as observations exist, varies between about 1 and 3 feet,

while absolute range during the last 7 years is 3 ft. 9 inches, a considerable difference from the very much larger estimates of travellers and others which have been given on pages 35–37.

The mean levels of the lake for each year from tbe Port Victoria-Kisumu gauge (corrected as before) are :—

ANNUAL MEAN LEVEL OF LAKE.

YEARS.	METRES.	FT. IN.	YEARS.	RATE OF CHANGE PER ANNUM.	YEARS.	TOTAL FALL OF MEAN LEVEL FROM 1896.
				Metres		Metres
1896	0·928	3 0·6	1896–99	−0·065	1896	..
1897	Incomplete.	..	..	..	1897	..
1898	"	..	..	..	1898	..
1899	0·733	2 4·9	1899–90	−0·342	1899	0·195
1900	0·391	1 3·4	1900–01	+0·117	1900	0·537
1901	0·508	1 8·0	1901–02	−0·336	1901	0·420
1902	[0·172]	0 6·8	1902–03	+0·570	1902	0·756
1903	0·742	2 5·2	..	..	1903	0·186
1904	0·917	3 0·1	1903-04	+0·175	1904	0·011

This table gives the mean level of the whole year for each year in which the observations are sufficiently complete. In 1902 the observations for April and May at Kisumu are missing, but the Entebbe and Jinja gauges for these months show that the level rose slowly and slightly during these months, so that no error is introduced by their omission.

It is evident, therefore, that there has been steady fall of the average lake level amounting in all to about 76 cm. during the 7 years 1896-1902, followed by a rise of 56 cm. during 1903.

The range for each year and the whole period is as follows :—

KISUMU GAUGE.

YEAR	MAXIMUM		MINIMUM		RANGE		REMARKS
	Reading	Date	Reading	Date	Ft. In.	Met.	
	Ft. In.		Ft. In.				
1896	3 8¾	14 January	2 2½	22-29 October	1 6¼	0.46	
1897	3 8	11-14 June	*	*	—	—	* Observations cease on 31 July.
1898							(No observations before September).
1899	3 7	21 May	0 11¾†	29 December	2 7¼	0·79	† A correction of 6″¾ made to all observations from 23rd August, 1899.
1900	2 2¼	10 May	−0 0¾	3-4 November	2 3	0·69	
1901	3 5¼	13 May	0 6¼	5 Feb. and 12 Mar.	2 11	0·89	
1902	—	—	−0 0¾	22 July	—	—	Maximum occurred in May, but Kisumu gauge readings for this month were lost, so max. and min. for Jinja are also shown.
" (Jinja)	1 11½	23 May	0 11	24, 27 and 28 Dec.	1 0½	0·32	
1903	3 5¼	17 June, 15 and 18 July and 3 August	0 9¼	1-2 January	2 8	0·81	
1904	4 6½	31 May	2 2	8 November	2 4½	0·72	
Absolute 8 years	3 8¾	14 January, 1896	−0 0¾	3-4 Nov., 1900, and 22 July, 1902	3 9½	1·16	

The conclusions which may be drawn from this study of the lake gauges are the following :—

1. The gauge records are trustworthy when the necessary corrections have been applied as above explained.

2. The Entebbe gauge, though of a very great interest in recording a local abnormal movement of the water level, due it is believed to local intermittent earth movement, is not a true record of the oscillation of the lake level.

3. The Kisumu gauge does truly record the lake oscillation, but about the Jinja gauge there is a slight doubt.

4. The annual oscillation is from 0·30 to 0·90 metres.

5. The period of the secular oscillation cannot be determined from so short a series of observations.

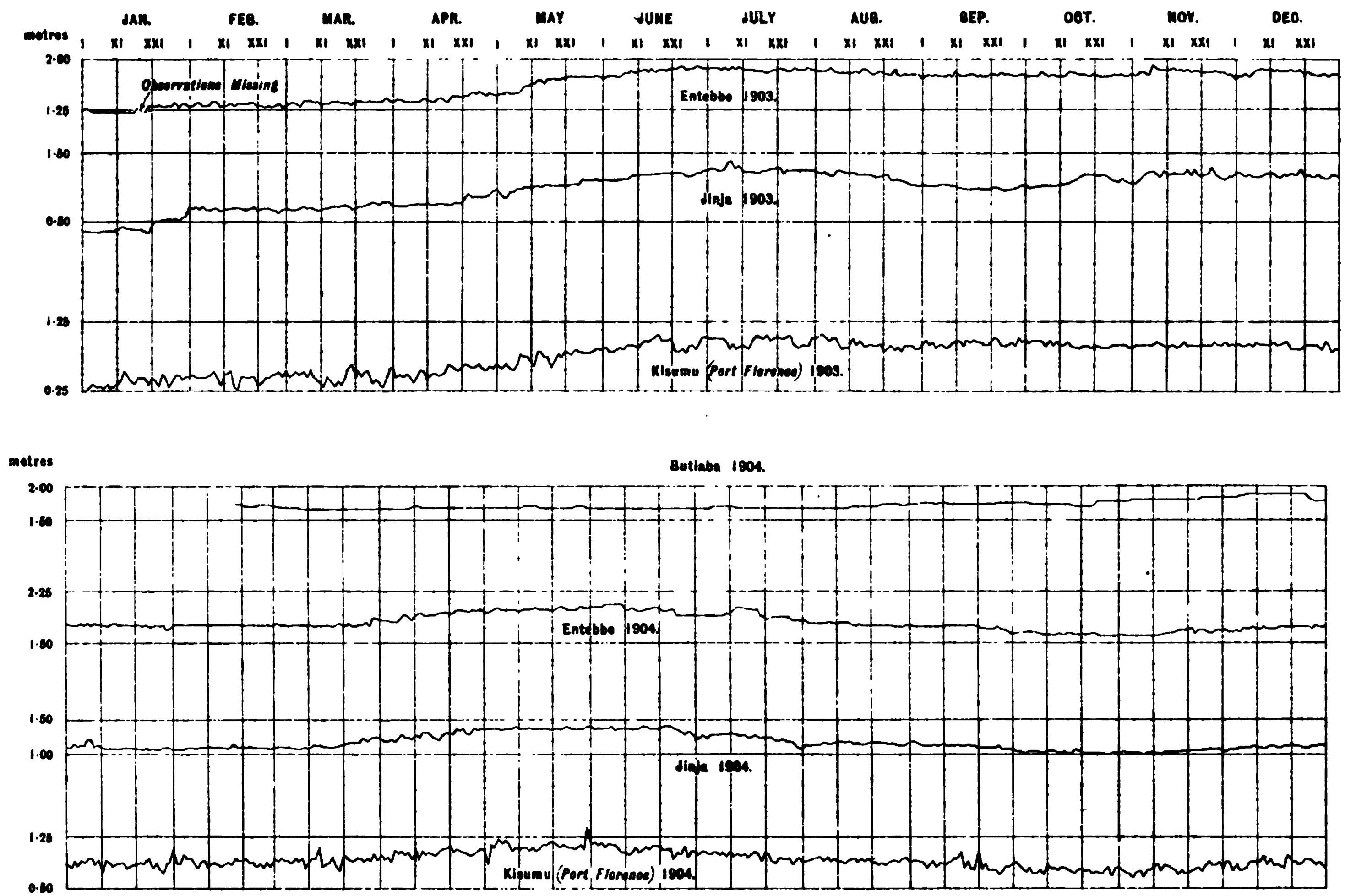
6. Between 1896 and 1902 there has been a fall of 76 centimetres in the average level of the lake, since followed by a rise of 56 cm.

7. 1878 was a high level period.
1880-90 was a falling level period.
1892-95 was a temporary high level period.
1896-1902 was a falling level period.
1903 was a rising period, and the level was maintained in 1904.

MEAN MONTHLY LEVELS OF LAKE VICTORIA (*in metres*).

DATE	STATIONS			DATE	STATIONS			DATE	STATIONS		
	Entebbe	Kisumu	Luba's		Entebbe	Kisumu	Luba's		Entebbe	Kisumu	Luba's
1896				**1897**				**1898**			
January ..	0·58	1·10	0·61	January ..	0·33	0·86	0·40	January ..	..	..	..
February .	0·51	1·03	0·55	February .	0·34	0·91	0·43	February .	..	..	..
March ..	0·44	1·01	0·54	March ..	0·36	0·93	0·42	March ..	..	..	..
April . ..	0·47	1·00	0·55	April . ..	0·43	1·01	0·50	April . ..	..	..	..
May	0·47	1·01	0·56	May	0·53	0·99	0·57	May	..	..	0·60
June . ..	0·43	0·99	0·53	June	0·56	1·07	0·61	June . ..	..	..	0·51
July . ..	0·42	0·92	0·47	July . ..	0·50	1·04	0·56	July . ..	..	..	0·54
August ..	0·37	0·88	0·43	August ..	..	..	..	August ..	..	..	0·51
September	0·27	0·79	0·36	September	..	..	..	September	0·74	0·99	0·50
October ..	0·15	0·71	0·26	October ..	..	..	..	October ..	0·99	0·99	0·95
November.	0·26	0·83	0·35	November.	..	..	..	November.	1·03	1·00	0·95
December.	0·35	0·87	0·40	December.	..	..	..	December.	1·08	1·00	0·95
Mean ..	0·393	0·928	0·468	Mean ..	..	..	..	Mean ..	..	..	..

LAKE Gauge Readings



Survey Department.

DATE	Stations: Entebbe	Kisumu	Luba's	DATE	Stations: Entebbe	Kisumu	Luba's	DATE	Stations: Entebbe	Jinja	Kisumu	Luba's
1899				**1900**				**1901**				
January ..	1·00	0·95	0·90	January ..	0·77	0·45	0·39	January ..	0·58	..	0·32	0·35
February .	1·01	0·91	0·87	February .	0·79	0·45	0·39	February .	0·61	..	0·37	0·36
March ..	0·99	0·89	0·85	March ..	0·80	0·43	0·38	March ..	0·77	..	0·43	0·48
April . ..	0·99	0·89	0·84	April. ..	0·79	0·48	0·42	April. ..	1·16	..	0·68	0·66
May.. ..	1·04	0·99	0·94	May.. ..	0·80	0·56	0·45	May . ..	1·53	..	0·95	0·89
June . ..	1·05	0·99	0·93	June . ..	0·83	0·53	0·45	June . ..	..	..	0·88	0·83
July . ..	1·03	0·82	0·86	July.. ..	0·86	0·43	0·45	July.. ..	..	..	0·65	0·68
August .	0·93	0·57	0·64	August ..	0·84	0·37	0·45	August ..	..	0·57	0·49	..
September.	0·80	0·52	0·48	September.	0·73	0·37	0·38	September.	..	0·39	0·42	..
October ..	0·75	0·42	0·38	October ..	0·53	0·19	0·24	October ..	1·18	0·45	0·35	..
November.	0·70	0·41	0·35	November.	0·45	0·16	0·16	November	1·13	0·33	0·32	..
December .	0·71	0·44	0·35	December.	0·48	0·27	0·26	December.	1·10	0·40	0·24	..
Mean ..	0·917	0·733	0·699	Mean..	0·722	0·391	0·368	Mean..	..	..	0·508	..

DATE	Stations: Entebbe	Jinja	Kisumu	DATE	Stations: Entebbe	Jinja	Kisumu	DATE	Stations: Entebbe	Jinja	Kisumu
1902				**1903**				**1904**			
January ..	1·07	0·83	0·18	January ..	1·27	0·42	0·37	January ..	1·75	1·10	0·85
February .	1·03	0·39	0·16	February .	1·33	0·68	0·43	February .	1·75	1·09	0·88
March ..	1·03	0·37	0·16	March ..	1·36	0·71	0·44	March ..	1·76	1·13	0·91
April . .	1·07	0·43	..	April . ..	1·42	0·78	0·52	April. ..	1·90	1·28	1·02
May.. ..	1·20	0·54	..	May.. ..	1·65	1·00	0·73	May . ..	1·99	1·37	1·11
June . ..	1·16	0 50	0·21	June . ..	1·85	1·15	0·91	June . ..	1·99	1·37	1·08
July . ..	1·11	0·44	0·17	July . ..	1·81	1·24	0·96	July . ..	1·91	1·24	0·98
August ..	1·08	0·42	0·14	August ..	1·81	1·14	0·91	August ..	1·77	1·15	0·91
September	1·06	0·39	0·13	September.	1·76	0·98	0·93	September.	1·73	1·12	0·85
October ..	0·99	0·35	0·14	October ..	1·77	1·07	0·91	October ..	1·62	1·03	0·77
November.	1·03	0·37	0·16	November.	1·81	1·16	0·90	November.	1·64	1·03	0·78
December .	1·23	0·36	0·27	December.	1·80	1·16	0·90	December.	1 71	1·10	0·86
Mean ..	1·091	0·412	[0·172]	Mean ..	1·638	0·958	0·742	Mean ..	1·793	1·168	0·917

The fourth class, daily oscillations, are usually of very small range. All bodies of water are influenced by the attraction of the sun and moon, but the tidal effect on inland lakes is usually so slight as to be demonstrated only on the largest lakes and by refined measurements. Lake Michigan which has an area about 25 % larger than lake Victoria has been shown by the U.S. Lake Survey to have a tide with an amplitude of 1½ inches for the neap tide, and 3 inches for the spring tide. [1] That of Lake Victoria has not yet been investigated with sufficient accuracy to determine its range.

Certainly the effect will be masked by the wind effect caused by the

[1] Russell, "Lakes of North America." Boston, 1900, p. 33.

lake breeze by day and the land breeze by night, and this will be much accentuated in a long narrow gulf like the Kavirondo Gulf at Kisumu. Here the gauge shows a daily oscillation which is sometimes very marked.

It comes out also in the monthly means which are given in metres in the following table:

KISUMU

1904	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
7 a.m. ..	0·85	0·88	0·91	1·02	1·11	1·08	0·98	0·91	0·85	0·77	0·78	0·86
4 p.m. ..	1·03	1·05	1·04	1·16	1·20	1·18	1·07	1·00	0·96	0·90	0·90	1·01
Difference.	+·18	+·17	+·13	+·14	+·09	+·10	+·09	+·09	+·11	+·13	+·12	+·15

Pringle[1] says that the maximum rise in a day due to wind and heavy rain was about two feet according to native information.

Gedge[2] notes the occurrence of small temporary rises of the lake at irregular intervals, and lasting for an hour or more. Pringle[3] states that he noticed a tidal movement of about 15 centimetres in Kavirondo Gulf, but it is doubtful whether this should not rather be attributed to wind action, which on the lake is reversed twice daily.

These phenomena are naturally accentuated in gulfs and long inlets, and at Entebbe from June to December, 1903, the difference between the 6 a.m. and 6 p.m observations in the monthly mean varied from $-0^{m}\cdot004$ to $+0^{m}\cdot003$ only.

Similarly Baumann[4] says that at Muanza there was a daily oscillation of 30 centimetres, and that in the Rugezi channel the water was 0·50 metre lower in the morning than at noon, though no such variation was noticed at Bukoba, on an open shore.

The fifth class of changes of level, viz., "seiches," certainly occur on the Victoria lake, although no precise study of them has yet been made. Lake waters are affected by changes in atmospheric pressure, and in some cases variations of level amounting to some feet have occurred in calm weather. Forel[5] has recorded a rise of as much as 1·87 metres on the Lake of Geneva, and on the American lakes even larger ones have been noted.[6] Smaller pulsations also occur which

[1] Geog. Jour. Aug., 1893, p. 137.
[2] Proc. Roy. Geog. Soc., 1892, p. 323.
[3] Geog. Jour. Aug. 1893, pp. 189, 137.
[4] "Durch Massailand zur Nilquelle," p. 42.
[5] "Handbuch der Seenkunde." Stuttgart, 1901, p. 80.
[6] E. A. Perkins, "The Seiche in American Lakes." American Meteor. Jour., Oct., 1893.

are not yet fully understood. It seems probable that the sudden variations shown occasionally by some of the Victoria lake gauges are of the nature of seiches, though the subject cannot be pursued far at present, as Entebbe is the only station in Uganda where there is a barometer. All accounts of the lake, however, mention particularly the violent thunderstorms the water spouts and cloud bursts which are experienced on the lake, and these all evidence large and rapid variations of atmospheric pressure occurring locally. Thus it is not surprising if the gauges show occasionally irregularities of a somewhat considerable range.

From this short study of the oscillations of the lake some interesting deductions may be drawn.

Though the rise to the May-June maximum is more marked than that due to the November rains nevertheless the effect of the latter is an important one. If the November rains are feeble the lake level continues to fall, though slowly, until about April, when the heavy rains begin and cause the lake to rise rapidly. This rise however is followed by a rapid fall, since in July, August and September evaporation is at its maximum; the equatorial rain belt lies further to the north, and the dry south-east trade winds sweep over the lake catchment basin. It will be seen that each year in which the November rains were sufficient to cause a rise in the lake, as in 1900 and 1902, the mean level of the lake in the following year showed an increase, while 1899 and 1901, in which the fall of the lake continued into the following year, were succeeded by lower mean levels. For of a given amount of water supplied to the lake in November, December and January, a much smaller percentage is lost by evaporation than there is of a similar amount received in the heavy rains of April and May, which are followed by the dry months. This is mentioned specially by Lugard, quoted above, as being the case in the winter of 1891, which was followed by exceptionally high lake, levels in 1892.

Since in the latter part of the rainy season of 1903 the rain was exceptionally heavy in the Nilotic provinces of Uganda in the Lake Albert basin and on the Victoria lake, the average level of the lake in 1904 was above that of 1903.

Taking the average discharge at the Ripon Falls as 575 cubic metres per second, this will give 49·7 million cubic metres per day and 1491 million cubic metres per month, or 17,925 million cubic metres per year. If the area of the lake surface is taken at only 65,000 square kilometres, the above discharge will represent a fall of the lake surface of about 22·5 millimetres per month. Taking the maximum discharge

at the Ripon Falls as 650 metres cube per second, corresponding to the highest level of the lake in 1903, the fall due to the discharge alone would be 25·6 millimetres in a month. If these falls per month are compared with the fall of the curves after the June maximum of Plate IV, it will be seen how powerful a factor evaporation is in July, August and September, in that it causes the lake level to fall in some years much faster than the above rate, in spite of all additions to the lake volume by occasional rainfall and what the tributary rivers are bringing in.

Except the Kagera the streams flowing into the lake are unimportant, while the average rainfall on the lake surface may be taken at 1500 mm. yearly, of which some 270 mm. is carried off by the Nile at the Ripon falls, leaving a depth of about 1200 mm. of water added to the lake besides all that the rivers bring in, of which the whole or a large part is removed by evaporation.

The difference between the total water added to the lake in any year and the sum of the quantity evaporated together with that discharged at the Ripon falls is represented by the difference between the levels of the lake at a year's interval, which is given in the following table for the last 8 years, but owing to the wind action on the water of Kavirondo gulf, at the head of which the Port Florence gauge is situated, it is probably more correct to take the difference between the mean level of months a year apart.

CHANGE OF LEVEL OF LAKE SURFACE.

MEAN	January 1 to December 31	MEAN LEVEL Jan. to Jan.[1]	MEAN	January 1 to December 31	MEAN LEVEL Jan. to Jan.[1]
	mm.	mm.		mm.	mm.
1896...	−300	−260	1901	+190	−140
1897...	+150[2]	+110	1902	−150	+190
1898...			1903	+610	+580
1899...	−640	−500	1904	− 20	−120
1900...	−200	−130			

The principal difficulty is to estimate, even roughly, the ratio of the run off to the rainfall on the basin. On the eastern side of the lake rainfall is from 700 to 900 mm., probably, and as the rivers rise and

[1] Mean level January, 1896, to mean level January, 1897, etc.
[2] From 1st January, 1897, to 31st December, 1898.

fall rapidly, 30% may be perhaps assumed as the run off. On the north and south of the lake the area is small and the rivers few and unimportant, except the Nzoya near Mumias. The western portion then is the important area; here rainfall is higher, probably reaching 1600 to 1800 mm., but the percentage which forms the run-off must be very low since, as already mentioned, account must be taken of the swampy valleys of feeble slope, the vast marshes in the middle course of the Kagera, and the rapid evaporation from the luxuriant vegetation in the dry seasons, when the trade winds sweep across the country. Under these conditions the run-off is probably a good deal less than is generally assumed, and may probably be as low as 12 or 15 per cent.

On account of the vast area of open water of lake Victoria, the humidity of the air in contact with it cannot vary greatly from year to year, and only to a small extent from month to month, judging from the relative humidity of stations round the lake; the winds on it are those caused by the diurnal reversal of lake and shore winds and even the south-east trade winds hardly seem to affect them. The evaporation consequently must differ little from year to year, and may be taken in the absence of actual measurements as about 1250 mm. per annum. Four days measurements in cloudy and showery weather near Entebbe in February, 1903, gave 3·4 mm. per diem for the evaporation from a free water surface and, though insufficient, the result is not incompatible with the assumption made.

Of the seven or eight stations near the lake, meteorological observations are only available from all of them for two or three years, but these results do not contradict the view that the rise and fall of the lake is principally due to the amount of rain which falls on it, and only secondarily to the supply from its catchment basin, which probably does little more than maintain the level for a short time after the rainy season has ceased.

The freshness of the Victoria lake water may be mentioned in this connection as showing that the river water is inconsiderable compared with that furnished directly by rainfall. It is river water which takes up portions of the various soluble substances met with in percolating through the ground, and carries them with it to the lake where they remain behind when the water evaporates. Both Albert Edward and Albert lakes are described as slightly brackish, as though river water supplied a larger proportion of their supply, still it should be mentioned that saline deposits occur on the shores of both lakes, which at Katwe, at any rate, are in close proximity to the old crater lakes and owe their origin to volcanic action.

This vast sheet of water known as the Victoria Nyanza or Lake Victoria covers an area which is estimated to be about 68,000 square kilometres, though no survey of the whole lake has yet been made with sufficient accuracy to determine its area with any precision since its discovery by Speke in 1862. It has been recognized as the source of supply for the Victoria Nile, though some have maintained the most distant source of the largest of the lake tributaries as being the actual Nile source. Still it is the lake, by pouring its surplus waters over the Ripon Falls, which provides the Victoria Nile with its water, and consequently the rise and fall of the lake level which directly affects the volume supplied to the Nile has always attracted attention. But when we come to discuss the Victoria Nile and its regimen we shall see that local conditions regulate this varying supply until 150 kilometres north of the lake its function as a supplier of the Nile's waters is reduced to furnishing some 550 cubic metres per second constantly throughout the year. Still, as an important inland sheet of water some account is due of its general features, and its tributaries. The Victoria lake lies at an altitude of 1292 metres above sea level,[1] filling a comparatively shallow depression on the surface of the plateau. As a rule its shores are low, and even where the hills come nearest to the waters edge they rise but 200 to 250 metres at most above it. To the geological structure of this basin are due the long gulfs and bays, and the numerous islands which line the shores, as well as the remarkable proximity of the watershed to the northern shore of the lake, as has already been mentioned. Situated on the equator, where atmospheric conditions are specially favourable to violent thunderstorms in the rainy seasons, voyagers on the lake are by no means free from danger, and the canoes of the natives closely hug the shore or keep near islands, where they can run for shelter when a storm threatens. The monthly and yearly quantities of rainfall which supply the lake have been already given, and it remains now to consider the volume furnished by the tributary streams, and that discharged at varying levels at the Ripon Falls, while there will still be the least known and probably the most important factor, evaporation, for which only the most meagre treatment is possible.

Of the numerous streams which fall into lake Victoria the majority are small and unimportant, having courses of only a few kilometres in length ; the larger ones are given in the following table from which

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[1] Uganda Railway Survey.

it will be seen that none of them except the Kagera are rivers of any size:

Place	Altitude of Source	Length	Near Mouth		Remarks
			Width	Depth	
	m.	km.	m.	m.	
North Shore:					
Sio	..	75	30	..	
Nzoya	2200	210	80	..	
East Shore:					
Nyanda	2100	110	..	..	
Kuya	..	70	20	..	
Itoa	..	..	3-4	2	
Mori	..	..	10-15	2-4	
Mara	2000	210	30-35	..	
Suguti	1500	30	4	2	
Ruwana	1400	160	20	7	Periodically dry.
South Shore:					
Simiyu	1770	120	15	3	17 Jan., 1899, Dantz. Often nearly dry (Fischer).
Moame	1250	60	25	1	
West Shore:					
Lohungati	1500	140	..	..	
Ruiga	1300	..	..	..	
Kagera	2200	690	100	10	
Ruisi	1500	190	..	..	
Katonga	1600	155	..	..	

Thus it will be seen that their sources lie at no great altitude, and from the moderate size of the whole catchment basin their courses are short; moreover to the east of the lake the rainfall is but a very moderate one (Shirati about 700 mm.), so that most of the eastern rivers run very low, if not altogether dry, in the dry seasons. In other parts of the basin the structure of the country is against any of them furnishing a large supply; they follow the fault valleys between the different blocks, which have been unequally elevated, and consequently they flow in valleys of low slope in which much of the supply is lost in the swamps and shallow lakes filling the valley floors in the rainy seasons; from July to September the basin is swept by the comparatively dry south-east trade winds (see humidity at Mbarara p. 23), which must cause rapid evaporation. It seems very doubtful, therefore, if the run-off can be put much higher than about 15% since the Nzoya alone, rising in mount Elgon, has a sufficient slope to deliver its waters

into the lake without heavy loss. This river is described[1] as flowing with a rapid current in a bed full of boulders, so that it is unnavigable, and only fordable in December, January and February, so that it would seem that there is no summer dry season in Mount Elgon where it rises; but Macdonald states that Elgon has two wet and two dry seasons, like the lake area.

Kagera river.—The Kagera[2] alone is a tributary of importance, which in the rainy season brings a large supply to the lake. Rising in the extreme southern portion of the Nile basin near the northern end of Lake Tanganika it follows a northerly course of about 600 kilometres, then turning eastward it falls into the lake just north of latitude 1° S. Crossed first by Speke[3] and Grant[4] in 1861 it was followed by Stanley for some kilometres in the middle portion of its course in 1876;[5] and crossed by him 13 years later in July, 1889,[6] when returning to the coast with the Emin Pasha Relief Expedition. Since then several expeditions have followed its course or crossed it at various points. From Dr. F. Stuhlmann who crossed it with Emin Pasha in February 1891 we get certain information, as well as from the account of his return journey in 1892.[7] In this year also Dr. O. Baumann[8] explored the upper reaches of the Kagera, and considered the source of the Ruvuvu as being that of the main stream. In 1894 Scott Elliot[9] followed a part of its course. In May, 1894, Count von Götzen[10] crossed the Kagera near its junction with the Ruvuvu, and indicated the Nyavarongo as being a more important tributary than the Ruvuvu and consequently the main source of the Kagera, which has since been maintained by Kandt who found it about 100 kilometres longer.[11]

Among the other travellers who have visited this district are Herrmann, Langheld, Ramsay and von Trotha,[12] also more recently the officers of the Anglo-German Boundary commission.[13]

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1 Hobley, "Geog. Jour." Oct. 1898, p. 362.
2 Fitzner. "Der Kagera-Nil." Inaug. Diss. Halle. 1899.
3 Speke, "A journal of the discovery of the source of the Nile." London, 1863, p. 263.
4 Grant. "A walk across Africa." London, 1864.
5 Stanley, "Through the Dark Continent." London 1878, vol. i, p. 450.
6 Stanley, "In Darkest Africa." London 1890. vol. ii, p. 352.
7 "Mit Emin Pascha ins Herz von Afrika." Berlin, 1894.
8 Baumann, "Durch Massailand zur Nilquelle." Berlin, 1894.
9 Scott Elliot "A Naturalist in Mid Africa." London, 1896.
10 Von Götzen, "Durch Afrika von Ost nach West." Berlin, 1895.
11 "Caput Nili," Berlin, 1905,
12 Von Trotha, "Meine Bereisung von Deutsch Ostafrika," Berlin, 1897.
13 Delme Radcliffe "Geog. Journ.", 1905, p. 481.

The mountainous ridge which forms the eastern boundary wall of the "rift" valley in which the Albert Edward, Kivu and Tanganika lakes lie, forms the water-parting between these and the Victoria lake basin, and the waters of the eastern slope supply the various tributaries of the Kagera river system, while those of the western slope flow to the western valley.

According to Baumann[1] the basin of Luvironza, the most southern tributary of the Ruvuvu river, is separated from the "rift" valley by the Kangosi Hills (1970 m.). From here the water-parting appears to have a north-easterly direction until it intersects the Uyogoma district between Kaponoras village and Rusengo, leaving to the east a barren hilly district draining partly to the Malagarisi river and Lake Tanganika, partly to the Lohugati and Ruiga rivers to Lake Victoria. The western portion, a plateau with narrow deeply eroded valleys[2] drains to the Kagera. From here it turns northward and then eastward passing between the Urigi lake and the Ruiga river until it almost reaches the Victoria lake, to which it now runs parallel until the mouth of the Kagera is reached[3] in latitude 0° 58′ S. The western limits of the Kagera basin are formed by the Ruampara hills in Mpororo.

On the ridge which encloses Lake Tanganika on its eastern side, in latitude 2° 55′ S, and on the flanks of a hill named Missosi ya Mwesi, Baumann[4] found the source of the Ruvuvu on September 19, 1892. From this point it flows at first eastwards for about 100 kilometres, when it turns to the north. At about 220 kilometres from its sources the combined streams of the Akanyaru and the Nyavarongo join it at a point of which the altitude is given as 1330 metres above sea level from von Götzen's hypsometric determinations. From this point it now flows northwards for 190 kilometres through a wide valley mostly occupied by swamps and shallow lakes as far as latitude 1° 5′ S.; in this distance the fall is very slight, but greater slope and higher velocity occur between this point and Kitangule beyond which it meanders through a level flood plain to the lake. The whole course of the river from its source to its mouth is about 600 kilometres.[5]

Commencing as two small streams scarcely half a metre wide, at an altitude of about 2120 metres, in a small rather swampy valley lying between steep grass slopes, the Ruvuvu soon increases as it receives

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[1] Durch Masailand p. 98. cf. Fitzner p. 8-10.
[2] Baumann, "Durch Masailand zur Nilquelle," p. 77.
[3] Stuhlmann. Mit Emin Pasha, p. 168.
[4] Baumann, pp. 88, 145.
[5] See page 6.

numerous small streams, and a day's march down the valley it is a rapidly flowing brook 5 metres wide. Baumann[1] crossed it lower down some 132 kilometres from the source in lat. 2° 50′ S. and gives the altitude as 1440 metres, which would give a fall of about 5·9 metres per kilometre. Here at the beginning of September it was a broad river with grey-brown waves which rolled between high banks covered with rich vegetation.

Though it was in the driest season, and at an unusually low level, he found it to be 35 metres wide and 3 metres deep, flowing rapidly; the banks were 3 metres high, and the flood marks clearly showed that they were topped in the rainy season. From this point it appears to flow in a well defined valley and in about lat. 2° 28′ S. is joined by the Akanyaru river on the left bank. This tributary was crossed by Baumann[2] at two points in about lat. 2° 50′ S.; at the lower point it was in two arms, one 10 metres wide and 5 metres deep, the other 5 metres wide and 1 metre deep, flowing slowly. At the upper crossing it was only a rapid hill stream, easily fordable.

While Baumann claimed to have reached the real sources of the Nile at those of the Ruvuvu in the mountains north east of Lake Tanganika, where its tributaries, the Luvironza and the Muverasi, also rise, others maintain that the Kagera continues upstream of the Ruvuvu and Ramsay found the Nyavarongo to be the upper portion of the Kagera. This stream rises in the hill Kuruhehe on the western boundary of Urundi, but the exact source is still uncertain. From here it flows north then east and then south round the Indidi hill range, to be joined by the Akanyaru to form the Kagera.

The Nyavarongo-Kagera up to the point where the Ruvuvu joins it is about 300 kilometres long.

The Nyavarongo where crossed by Count von Götzen in May 1894 was 40 metres wide, 4-5 metres deep and had a rapid current; this would give a discharge of about 400 cubic metres per second.

At its junction with the Akanyaru, the Nyavarongo was in March, 1897, 43 metres wide, 1·75 to 3·75 deep with a slight current, thus having a discharge of about 40 or 50 cubic metres per second.[3]

The Ruvuvu at the Ruanilo ford (1410 metres) is said by Baumann, September, 1892, to be 35 metres wide, 3 metres deep, and rapid; say 250 cubic metres per second; while, at its junction with the

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[1] Loc. cit. p. 146.
[2] Loc. cit. pp. 83, 146.
[3] "Expedition nach Ruanda," Verh. Ges. f. Erdkunde, Berlin, 1898, p. 312.

Kagera, it was measured by Ramsay, March, 1897, with the following results:—

Width	29 metres	
Depth	5·5 „	
Velocity... ...	0·92 „	per second

giving a discharge of about 150 cubic metres per second.

From this junction point the Kagera flows northwards in its wide north and south valley for a distance of some 170 kilometres falling from 1330 to 1310 metres in this distance. Throughout this part of its course it flows in a wide marshy valley which it partly submerges in times of flood; its breadth is given as from 2 to 15 kilometres, and possibly at flood stage it is in connection with the lakes Ihemi, and Kasingeni which lie in depressions opening on to the valley.

At Latoma the Kagera turns abruptly to the right and flows about 100 kilometres in a valley 15 to 20 kilometres broad and bounded by high hills as far as Kitangule; in the upper part between Latoma and Kitoboko are numerous rapids according to Langfeld. Below Kitangule it flows through a level alluvial plan, into which it has deeply cut its channel leaving banks 20 metres high which reduce gradually in height as the lake is approached.[1]

At Latoma in August, 1894, as measured by Scott Elliot the water channel was 36·5 metres wide, very deep and flowing 1 metre per second. If the depth were 8 metres this would give about 300 cubic metres per second. At Kitangule the breadth is given as 60-70 metres, depth 9-11 metres, and the velocity 1·5 to 2 metres per second for the period February to April. These data give a minimum discharge of 600 cubic metres per second and a maximum of 1500 cubic metres per second.

At the mouth in October, 1892, Count von Schweinitz gives

Width	80-100 metres
Depth	10-12 „
Velocity...	rapid.

If this last is taken at 1·5 metre per second the discharge will be about 1500 cubic metres per second. The approximate length of the Kagera, from the junction of the Ruvuvu to the Victoria lake, is about 390 kilometres.

In the rainy season of 1891, at the beginning of April, Stuhlmann[2] crossed the Kagera in lat. 1° 3′ S. at Kavingo, and found it 50-60 metres

[1] Von Schweinitz, "Deutsch Ostafrika in Krieg und Frieden."

[2] Mit Emin Pascha ins Herz von Afrika, Berlin, 1894, p. 247-9.

wide and very deep. Its yellow water flowed rapidly between belts of papyrus which lined the banks. The level of this point he states to be but little above that of the Victoria lake.

On July 26, 1889, in the dry season, Stanley[1] crossed it rather below this point, and describes it as 110 metres wide, 2·7 metres in average depth, and flowing with a velocity of 0·5 metres per second, which would give a discharge of about 150 cubic metres per second.

In the middle of the rainy season of 1892, Stuhlmann[2] crossed the Kagera at the village of Kayusa rather above Kavingo. It was here 40 metres wide in its open part, but on each bank there was a fringe of papyrus 60 metres wide and Nymphaca, Stratiotes, waterlilies, Chara, Utricularia, Atrolla, were collected there. It flows through an open valley, which becomes swampy near the river.

At Kitangulé about 60 kilometres from where it flows into the lake Stuhlmann crossed it in February 1891,[3] and found it 60 metres broad and several metres deep, flowing throngh a level grass plain in which it had cut its bed so as to leave banks of grey sandy clay 10-15 metres high. A thin layer of white infusorial earth appeared to indicate a former extension of the lake. A belt of high papyrus linea the banks.

Speke[4] crossed at this point on 16th January, 1862, and describes it as 70 metres wide, sunk to a considerable depth below the surface of the land, and flowing with a velocity of 1·0 metre to 0·75 metre per second.

In January, 1891, Stuhlmann[5] noted that the Kagera flowed into the lake latitude 0° 58′ S by three arms, of which the largest was 100 metres wide; at the mouth of each was a considerable bar on which the water was so shallow that a canoe could not cross it, showing that in flood the river brings down a considerable amount of material in suspension.

It has been maintained[6] that the Kagera is the actual upper course of the Nile, and that before the subsidence took place which formed lake Victoria, the Kagera flowed between the Sesse Islands and the western shore, then skirted the present northern shore by Rosebery Channel to Napoleon Gulf to join the Nile at the Ripon Falls; a distinct current is also mentioned as setting across from the Kagera to

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1 In Darkest Africa, II, p. 353.
2 Loc. cit., p. 661.
3 Loc. cit., p. 220.
4 Journal of the discovery of the source of the Nile, p. 222.
5 loc. cit., p. 168.
6 Johnston. "The Nile Quest.", London, 1904, pp. 266, 302.

the Ripon Falls. Seeing how small an effect the volume discharged by the Kagera, even in the rainy season, can have on the water of this vast lake any such current must be an effect of the prevalent winds, and as we have seen that winds blow from lake to shore by day at almost all seasons, it is more than probable that in places a regular drift of the surface water may be caused. Considering the vast area, about 68,000 square kilometres, covered by the waters of the lake it must be some time before the depths of the central portions are known with any accuracy. At present only along the shore belt, some ten kilometres wide, of the northern portion have systematic soundings been published,[1] and these show depths up to 60 metres (200 feet), the deepest sounding being 80 metres (269 feet) off the east coast 3 kilometres west of Kitua. On the basis of these insufficient data it seems premature to say that an elevation of 240 feet would show a converging network of river channels uniting with the Kagera and the main stream of the Nile,[2] since there would be a slope, at times somewhat steep, from the northern shore of the lake across the line between the Kagera mouth and the Ripon falls, and probably continuing to deeper and more central parts of the lake.

Nor can the water flowing out of the lake at these falls have any appreciable effect in producing such a current since, compared with the lake water, the amount discharged is so small as to cause a perceptible current for some few kilometres only.

The volume of water discharged at the Ripon falls has been worked out by Mr. J. I. Craig on the basis of a discharge measured by Sir William Garstin on January 22, 1903, which gave a volume of 549 cubic metres per second when the lake gauge at Jinja was reading 0·51 metre. From this the following discharge table was computed[3]:—

JINJA

Gauge Reading	Discharge	Gauge Reading	Discharge	Gauge Reading	Discharge	Gauge Reading	Discharge
Metres	Cubic metres per second	Metres	Cubic metres per second	Metres	Cubic metres per second	Metres	Cubic metres per second
0·0	495	0·4	539	0·8	583	1·2	627
0·1	506	0·5	550	0·9	594	1·3	638
0·2	517	0·6	561	1·0	605	1·4	649
0·3	528	0·7	572	1·1	616	1·5	660

[1] Chart published by the Admiralty.
[2] Johnston, loc. cit.
[3] From App. IV, of "A report on the Upper Nile."

The Victoria Nile. —The Victoria Nile on leaving the Ripon falls flows down the reverse slope of the ridge which forms the northern shore of the Victoria lake, in a series of falls and rapids until Kakoji is reached, a distance of some 65 kilometres; beyond this the river enters a low-lying tract between this ridge and the rising ground of Shuli province. This area has the appearance of being a trough between two orographic blocks similar to that in which the Kagera forms its wide swamps, and here lie the shallow lakes of Choga, Kwania and the wide mouth of the river Seziwa. The variation of the discharge at the Ripon falls in a year such as 1903 varies about 10 % on either side of the mean amount but such a variation can have no effect on the area of lake Choga.[1] This area of open water measured on the map is about 2900 square kilometres, so that a rise of even 1 centimetre a day would mean an addition of about 330 cubic metres per second without taking evaporation into account.

Its altitude has been given as 1010 metres above sea level but this would seem to be somewhat low; Mruli has been given as 1070 metres and Foweira as 1060 metres,[2] but where the differences of level are so small, isolated hypsometric or aneroid determinations are not reliable. The whole reach from Kakoji to Foweira is a flat basin, and the slope must be extremely small, so that the difference of 10 metres between Mruli and Foweira over a distance of 72 kilometres, which would correspond to a slope of 1 in 7,200, must be too great; probably 5 metres is as much as should be allowed, and if Foweira is taken provisionally as 1060 metres, Mruli and Lake Choga should not then be more than 1065 metres, giving a fall of about 64 metres from the Victoria lake to Kakoji.

Lake Choga[3] is a shallow sheet of water, the depth varying from 4 to 9 metres, with low marshy shores; the rivers which drain into it enter at the head of wide gulfs, which are rather arms of the lake than true river channels. Groups of hills occur at one or two points rising from 100 to 400 metres above the lake, but generally the country between lake Victoria and lake Choga is very flat and closely wooded on the right bank of the Nile, becoming somewhat hilly in the southern portion, near the Victoria lake; on the left bank lies the flat wooded country of Uganda, part draining to lake Choga, and the western portion to the Kafu river which joins the Nile at Mruli Throughout this part the regular northward slope of the country is

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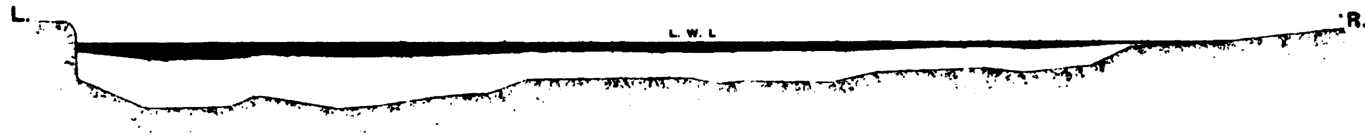
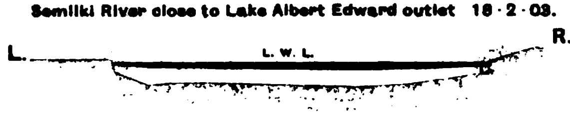
[1] Report on the Basin of the Upper Nile, p. 73.
[2] Vandeleur. Geog. Journ., April 1897, p. 390.
[3] Kirkpatrick. Geog. Journ., April 1899.

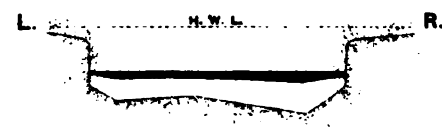
Victoria Nile about 15 Km. downstream of Murchison Falls 20 · 8 · 03



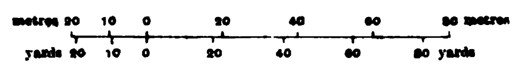
Semliki River close to Lake Albert Edward outlet 18 · 2 · 03.



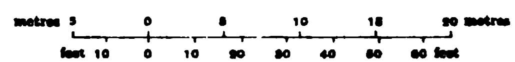
About 50 Km. upstream of Albert Lake



HORIZONTAL SCALE 1 : 2,000



VERTICAL SCALE 1 : 500



Monthly mean level of Lake Victoria, Kisumu Gauge

* observations missing

well shown by the direction of the streams, which has probably been determined as suggested (p. 19) by the tilting of this block of country to form the Victoria lake.

The Kafu joins the Nile at Mruli, having risen in the hills south of Hoima and flowed in a north-easterly direction to Mruli receiving the Kitumbui, Maanja, Lugogo and Dubenge on its right bank, and a number of short streams on the left bank. Near its source it is a clear rapid stream with marked periodicity as far as Barawana, 66 kilometres, but soon after passing this point, where the Kampala road crosses it south of Hoima, it enters a level plain and flows as a steady stream with dense brakes of papyrus on either bank, while swamps are formed in low-lying ground by its tributaries where they join it. It is about 30 metres wide at Mruli, 85 kilometres from Barawana, where it joins the Nile after a total course of 150 kilometres, and adds a volume of water which probably varies but little since in the lower reaches the Kafu shows no marked rise in flood.

The same holds good for the Nile itself between Mruli and Foweira where the water-level hardly rises even in the rainy season. We have seen that the volume of water discharged from the Victoria lake at the Ripon falls varies from month to month and from year to year, according to the level of the lake; this water flows down the Victoria Nile into lake Choga, where these variations have but a very small effect on the large water surface, and consequently the supply of the Victoria Nile at Mruli only varies within very narrow limits, while that of the Kafu does the same. Between Mruli and Foweira the Nile flows as a broad and deep stream with a steady but not rapid current; it is free from sand banks since the material taken up in the upper reaches has been deposited in lake Choga. In breadth it varies usually from 270 to 360 metres but in places, as at Mruli where the Kafu joins it, it reaches 700 metres. From Mruli to Koki a distance of 20 kilometers the solid low bank is thickly fringed with papyrus which does not however extend inland, except at the mouth of the Titi river, where there are low marshes for about 100 metres from the river. Beyond Koki the bank is higher being from half a metre to a metre in height. The right bank is for the most part high and solid, papyrus only occurring in places, and the country is generally open and park-like, with here and there patches of thick forest. The water level is very constant, the rise between the wet and dry seasons being very small; some flooding occurs in the rains where tributary streams join, but this is of small extent.[1] The Titi is the principal stream

[1] Communicated by Captain R. Owen.

on the left bank while on the right there are the Kola, Lenga, and Toshi rivers.

It follows therefore that the effect of lake Victoria and its basin on the supply of the Nile is to furnish between Mruli and Foweira a volume which varies but little from its mean value either from month to month or from year to year; also this amount is probably about 550 or 600 cubic metres per second, this being the volume measured below the Murchison falls on March 20, 1903[1] the end of the dry season when the tributaries which join the Nile between Foweira and the falls are dry. High or low lake levels, wet or dry seasons, cannot alter this quantity appreciably, since the level of the vast low-lying area occupied by lake Choga, its marshes, and the other lakes which join it, only varies within very narrow limits; we may say, with some confidence, until actual measurements are available, that the discharge of the Victoria Nile above Mruli closely approximates to 570 cubic metres per second with a variation of perhaps 50 above and below this value, and this value represents the part played by the Victoria lake, its basin, and its rainfall in supplying the Nile. At Foweira (1060 metres) 274 kilometres from the Ripon falls, the Nile turns sharply westwards and as a strong stream 450 metres wide dashes down the Karuma falls and then flows in a succession of rapids and open reaches till the Murchison falls are reached.

To the west of this Mruli—Foweira bend the country is low and undulating in character, and Mount Fumbi (1400 metres) may be called the centre of dispersion for the drainage of Unyoro as it is the highest point of the SW. to NE. ridge on which are Hoima and Masindi and which runs parallel to the Albert lake, dividing the drainage which flows to that lake from that which flows to the Kafu river and the Nile. The rock of this part of the country seems to be the archaean granite or granitoid gneiss, forming ridges and isolated hills which project above the flat alluvial plains of the country,[2] where a few streams of small importance flow to the Victoria Nile.

At Foweira the Lenga and the Dukhi rivers join the Victoria Nile on the right bank, and further down several others come in from the north. All these right-bank streams come from the high ground of Acholi, and must add largely to the volume of the Nile in the rainy season; their effect is seen in the sand banks which occur in the bed of the stream below the Murchison falls[3] and the delta which is

[1] A report on the Basin of the Upper Nile, p. 75.
[2] Vandeleur, loc. cit., p. 374.
[3] Report on the Basin of the Upper Nile, p. 75.

forming near Magungo where it enters the Albert lake. Since all suspended matter up-stream of Mruli is deposited in lake Choga, all that accumulates below the Murchison falls must have been derived from its bed between these falls and Foweira, or have been brought in by the right bank tributaries.

The Murchison falls, first seen by Sir Samuel Baker,[1] are about 44 metres in height;[2] the river narrows to 70 metres broad and finally rushes through a narrow gorge into the valley below. Of these falls Mr. Betton writes as follows :—[3]

"Close to Fajao are two isolated masses of biotite gneiss, and undoubtedly the river, which is here confined in a deep cañon, has carved its way eastward for one-and a-half miles to the present falls, leaving these masses as 'witnesses.'

"Arriving at the 200 foot basin into which the fall takes its final plunge, one notices how the constant spray from the falls, ascending in clouds like steam, allows the luxuriant vegetation to grow over even the vertical cliffs surrounding the basin on three sides, except where the soft mica schist has caved in by weathering. A double rainbow added to the beauty of the scene, but the near view of the falls is distinctly disappointing.

"The peculiar intermittent roar could now be accounted for ; a mass of water tumbling headlong into the pool is immediately followed by an enormous broken wave, then comes a lull, and the process is repeated. As this phenomenon was inexplicable from below, I suggested that a climb to the top of the falls was advisable ; and after much discussion our Nubi guide extracted from an airily clad Mnyoro the information that a track did exist to the top of the south cliff.

"It proved to be a most trying 200-feet climb up a steep slope covered with dense grass, and it could only have been made by an energetic European. A short downward scramble led to a rock plateau with potholes, the largest of which was 15 feet diameter and 10 feet deep, filled with water, marking the level of the former bed of the river when it swirled round a mass of gneiss in its centre. This being gradually worn away on the south side, apparently exposed a softer vein, and the river has cut its way through in a deep vertical cleft from 20 to 30 feet wide, and of unknown depth. A well-known officer in the Uganda Rifles whom I met two days later, informed me that he had measured the narrowest portion accessible, and found it only 18 feet wide.

[1] Jour. R. Geog. Soc. 1866. p. 1-18.
[2] Report on the Upper Nile, p. 74-5.
[3] Nature. June 19, 1902, p. 188.

"Now the Nile above this is a succession of falls, and, after a sharp bend to the north-west, turns again west when it is 200 feet wide and, gradually narrowing, tumbles 10 feet over a rock ridge spanning the river, and then over a 5 foot ridge. For 50 feet it rushes with increasing velocity and finally enters the extraordinary cleft. Down this, for 150 feet, the river 'slithers,' a solid mass of water, as if through a sluice. Suddenly it meets with an obstruction, a harder layer of gneiss through which in undercutting its way, with terrific force strikes this, and rebounds, sometimes with a huge shower of spray. Meanwhile the body of water behind has to find an outlet, and, still confined between high walls, is forced over the ridge with irresistible force ere, 250 feet further on, it tumbles over the last fall into the large basin below, and the back wave now a vast boiling mass, follows hard after it. This explains the peculiar sound of this fall."

A kilometre and a half down stream of the Murchison Falls is the post of Fajao where there is a ferry across the river. At this point there is said to be no rise of the water level throughout the year; huts on a low sandy flat only 0·4 to 0·5 metre above the water, can be occupied throughout the year, and the rope, posts, etc., of the ferry never require to be moved. The slope is fairly steep and the river flows with a high velocity. The volume discharged was measured on March 20, 1903[1] at a point about 10 kilometres below Fajao and 22 kilometres from the lake, which gave the following result: (Plate VI. fig. 2).

Width ... ... 307 metres	Mean velocity 0·645 metre per second.
Maximum depth 4·5 ,,	Sectional area 894·4 square metres.
Mean depth ... 2·58 ,,	Discharge 577 cubic metres per second.

From this the slope of the water surface was computed to be 1 in 18,500. Marks of a higher water-level one metre above the level at that date were noticed but it is certain that this was much more due to the variation of the lake level than to the flood rise of the river, and consequently the discharge table derived from this discharge is unreliable, as it is assumed that all rise of the water level is due to an increased volume of water coming over the Murchison Falls, and the rise of the lake is not sufficiently allowed for. When the discharge was measured it may be said with considerable accuracy that the volume of water passing over the falls was at its minimum; the constant discharge of the Mruli-Foweira reach was not being increased since the rains in the Acholi hills to the north of the river had not begun. By December

[1] A report on the Basin of the Upper Nile, p. 75, and Plan VIII. d.

the lake had risen about one metre, and by the following March it was probably 0·7 metre higher than in March, 1903, while at the discharge station the water level must have risen by a somewhat less amount, although the volume discharged would be the same since the supply passing the Murchison Falls must always be practically the same at this season when the tributaries below Foweira supply nothing. There is no doubt an increase, probably a considerable increase, in the volume which passes the Murchison Falls in the rainy season, but to measure that, a gauge and a series of discharge measurements are needed above the falls; below them the varying level of the lake in different years and in different seasons prevents any discharge table being made at present. [1]

Lake Albert Edward.—Lake Albert Edward was discovered by Stanley in 1875 and verified by him on his journey in 1888-9, but the shores of this lake have been laid down with greater exactness by Stuhlmann [2] (1891) on the west side, by Moore [3] (1899) on the west and north sides, Scott Elliot, Grogan (1899) and Gibbons [4] (1900) on the east side, and Scott Elliot [5] (1895), Lugard [6] and Stanley on the north side, all except Stanley and Lugard having approached the lake from the south.

The catchment basin of the lake includes an area of about 18,000 square kilometres of very irregular shape, which extends from the watershed north of Lake Kivu, in about latitude 1° 20′ S, as a belt some 50 to 60 kilometres wide down to the southern margin of the lake; here it widens slightly being bounded on the east and west by the high cliffs of the valley. Its north-eastern extension, lake Dueru, receives all the drainage of the eastern side of the Ruwenzori range.

At the southern end of the lake the continuation of the valley extends away to the southward where its floor rises gradually till it is finally blocked by the mountain masses of the volcanoes Kirungachamoto and Kirunga-chagongo which rise to heights of 3700 metres and 4000 metres and completely block the valley at this part (latitude 1° 30′ S).

At the foot of this mountain mass at an altitude of about 1500 metres is the source of the river Ruchuru which flows through

1 Cf. App. IV. of a Report on the Upper Nile.
2 "Mit Emin Pascha ins Herz von Afrika," 1894.
3 "To the mountains of the Moon," London, 1901,
4 Geog. Jour.. Feb., 1901.
5 A Naturalist in Mid-Africa, London, 1896.
6 Proc. R. Geog. Soc., December, 1892.

an open plain[1] covered with euphorbias, acacias, clumps of trees and yellow sunscorched grass; close to the lake it is a flat treeless plain extending up to the foot of the western hills which rise steeply some 18 kilometres beyond the village of Vichumbi; this plain ends in the belt of dark green reeds which fringe the lake almost everywhere.

Along the western shore the steep hill-slopes, which reach a height of from 300 to 500 metres and in places 600 to 900 metres above the surface of the lake, come very close to the shore so that there is sometimes only a space of a few metres broad between the foot of the hills and the lake, and at some points it is necessary to climb over the spurs which project into the water or to wade round them. Often when the mountain torrents are in flood the land track is impassable, and the only means of communication is by canoes. To the north-west of the lake the western wall of the rift valley extends northwards, enclosing the Semliki valley, and a grass plain extends for from 15 to 20 kilometres to the first low foothills of the great Ruwenzori range. Moore writes "a fringe of swamps borders all the northern shore and close to a low reed-covered promontory at the western end of it is the outflow of the Semliki river. Beyond (*i. e.* to the east of) this effluent the coast again closes in to the north as a swamp. There were low beaches of yellow sand over which the surf broke in endless lines of foam, and beyond these, reeds and trees standing in clumps, trees fallen this way and that, and trees half submerged in still pools of gleaming water, which stretches away among their rotting stems. After travelling in this way for two days through endless sheets of water and morass, where it was often impossible to tell where the swamp ended and the lake began, the coast bent to the south and we were within one day's (canoe) journey of Fort George.[1]" On the east side of the lake the hill slopes of the plateau keep from 5 to 10 kilometres from the lake as far as latitude 0° 30′ S. and then maintain a southerly direction towards lake Kivu. The shore of the lake is in this part flat, sparsely populated and without interest. Several streams intersect this plain and flow into the lake, of which the margin is low and swampy, usually fringedwith a belt of reeds more or less wide. The water is shallow, being but 5 metres deep at a distance of a kilometre and a half from the shore near Katwe according to Stanley.

Climate.—Except some rainfall observations at Fort Portal, north-east of Ruwenzori, no meteorological data exist for this part but it may

[1] Moore, loc. cit. p. 255 and p. 266.

be assumed that the climate is much the same as that of the Ankoli district except near the mountain range where the rainfall is probably much heavier. The vegetation at the south end of the Ruwenzori range is said however to indicate but a moderate rainfall.[1]

The run-off is carried to the lake by numerous streams, none of which are of any great size or importance, but the principal ones are:—

On the south:

Ruenda,[2] 5-6 metres wide, 1 metre deep and flowing rapidly in May 1891.

Ruchuru, 50-60 metres wide, 1 metre deep with a slow current[2] in May 1891, while Moore[3] in February 1900 describes it as "a mighty stream of muddy yellow water as wide as the Thames at Westminster and whirling in eddies and rapids away to the north."

On the west are only small torrents with deeply eroded beds which course down the steeply sloping ravines which they have cut in the cliffs of the western plateau. On the north is the only effluent, the Issango or Semliki (see p. 68). The eastern side contributes a few small streams only on account of the nearness of the Ankoli plateau but the Dueru lake receives from the slopes of Ruwenzori near Fort Edward five mountain torrents on its western shore which are impassable when in flood, while on the eastern there are the combined streams of Nasongi and Dura, as well as the larger river of Mpango; this latter is said by Lugard[4] to supply probably a larger volume of water than that carried off by the Semliki. Its headwaters lie in the neighbourhood of Port Portal.[5]

Change of level.—There are indications of a recent change of level in the Albert Edward lake similar to those which are met with in most other lakes in this part of Africa. As Moore[6] points out, the comparatively recent volcanic out-burst which has cut off lake Kivu from the rift valley to the north, has considerably reduced the supply of water flowing to the Albert Edward and Albert lakes compared to what there was in earlier times before the changes of level occurred which were due to the resulting earth movements; besides which there are the periodic variations of level which are probably due to varying

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1 Johnston. "The Uganda Protectorate" London, 1902, vol. I, p. 142.
2 Stuhlmann, loc. cit., p.265.
3 "The Mountains of the Moon," p.255.
4 Proc. R. Geog. Soc. 1892, p.837.
5 For fuller details of the rivers on the east of the Ruwenzori range, see "A Report on the Upper Nile," p. 48 ff.
6 Loc. cit. p. 222-4.

meteorological conditions, similar to those of the Victoria lake which have been discussed.

On the north and east sides of the lake, up to an altitude of 100 metres above its present level, there is a series of well marked shore lines[1] which outline the former limits of the lake; these sweep round the southern flanks of the Ruwenzori range into the Semliki valley where a barrier must once have retained the waters of the lake. Until this valley is more accurately known it is difficult to speak more precisely as to the nature of this dam.

Stuhlmann[2] records a layer of shells on the plain west of Vichumbi one metre thick and at an estimated height of 8 metres above the present level of the lake. The inhabitants of Vichumbi also possessed a tradition that in the days of their fore-fathers their village was situated at the foot of the hills.

As regards periodic oscillations Stuhlmann was told that the inhabitants of the small promontory of Kisira at the south end of the lake are driven out by their land being flooded every 6 or 7 years. When he revisited the spot in 1892, a year later than when he first reached it (May 1891) the lake appeared to be 20 to 30 centimetres lower, but any weakness in the November-December rains or lateness in the spring rains would account for this.

This observation appears to be the nearest approach at present to a record of the annual rise and fall of the lake, which doubtless has also its periods of higher and lower level as we have seen in the case of lake Victoria, and since the cause is meteorological all these equatorial lakes will vary similarly and at the same time. In February, 1903, when Sir William Garstin visited lake Albert Edward the Victoria lake had risen but slightly above its lowest level of recent years, so that the shore line marking the limits of the lake one to two metres higher than it then was[3] may mark the range of the lake level at the present time.

By the end of 1904, like all these lakes, it was probably a metre higher at least. This general rise was due to the rains of 1903 and 1904 and lake Rukwa, which about 1896 was almost dry, is now full again.[4]

The Semliki River.—The Semliki river takes the surplus water of the Albert Edward lake and flowing northwards in the valley to the

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1 A Report on the Upper Nile, p.41.
2 "Mit Emin Pascha ins Herz von Afrika," p.269.
3 A Report on the Upper Nile, p. 43.
4 Globus, vol. 87, No 5, p. 84.

west of the Ruwenzori range receives the drainage of its western slope as well as that from the western side of the valley; it reaches the southern end of the Albert lake after a course of about 260 kilometres of which the greater part has not yet been mapped, so that this length is only approximate. Like most central African rivers it is known by different names to the different tribes on its banks; Stanley called it the Semliki when he reached the northern end of it near the Albert lake, Stuhlmann found it known as the Issango on the west bank near the Albert Edward lake, while at Katwe it is known as Kakunda;[1] lower down Kabibi, Ituri and Nausa are also used.[2]

The breadth of the main valley between the steep slopes which divide it on the west from the Congo basin and the foot hills of the Ruwenzori range is from 20 to 30 kilometres, in the centre of which flows the Semliki in the narrow valley 1 to 2 kilometres wide which it has carved for itself in the alluvial deposits which cover the floor of the larger valley. This valley is wooded near the foot of the hills, and the numerous streams flow rapidly down their wooded ravines to join the main stream. About 75 kilometres from the head near Fort Mbeni the Semliki enters a part of the great Congo forest and little is known of its course until it emerges from it at the commencement of the level plains of the Albert lake.

Besides Stanley[3] in May 1889 the valley was traversed by Lugard[4] in 1891 and also by Stuhlmann in the same year[5]; Scott Elliot[6] marched round the southern end of the Ruwenzori range and ascended it from the western side to a height of 3100 metres while Stuhlmann's highest point was about 4,060 metres.

Where travel is so difficult and the forest growth hinders all detailed work, ample hydrographic material cannot be expected. The rainfall has been measured at Fort Portal (to the north-east of the Ruwenzori range) for about 3 years and amounts to about 1500 mm. yearly (see p. 31,) but this cannot be taken as representing the amount which falls on the lower slopes of the Semliki valley, where in the forested parts the rain probably falls throughout the year. Still the vegetation appears to absorb the greater part of it at once and in spite of the numerous tributaries (25 being shown on the right bank and 47 on the left bank

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1 Report on the Upper Nile, p. 67.
2 Stuhlmann.
3 In darkest Africa, vol. II p. 236-264.
4 Proc. Roy. Geog. Soc. 1892, Dec., p. 836.
5 "Mit Emin Pascha ins Herz von Afrika."
6 A Naturalist in Mid-Africa, p. 90

on Moisel's map), some of which are fed by the snow-fields and glaciers, the final discharge of the river into the Albert lake is only about 125 cubic metres per second in the dry season. The only two accurately measured discharges were taken in the dry season of 1903.[1] (see Plate VI).

PLACE	Date	Width	Mean depth	Section area	Mean velocity	Discharge
		m.	m.	m^2	m.p.s.	m^3.p.s.
Near Lake Albert Edward ...	18 Feb.	100	1·35	130	0·695	90
50 km. upstream of Lake Albert	4 March	68	1·90	121	0·960	116

The data furnished by travellers are imperfect, so that the volume discharged at other seasons can only be roughly estimated.

At about 50 kilometres down-stream to the SW. of the main mass of Ruwenzori, Stuhlmann[2] found the Semliki in June 1891 at Mkorongo flowing in a bed eroded to a depth of 6 to 10 metres in the alluvium but being here too deep to ford he crossed it 3 kilometres lower down where it was 60 metres wide, 1·25 metres deep, and its light yellow water was flowing very rapidly over a sand and gravel bed.

Lugard crossed it about 20 kilometres further down without difficulty about the end of the same year.

Near where it was crossed by Stuhlmann in June 1891, Stairs visited it in June 1889. He describes it as 38 metres wide 3 metres deep between banks 15 to 18 metres high, and having a velocity of about 1·33 metres per second (3 miles an hour)[3] which would correspond to a discharge of about 152 cubic metres per second.

About 75 kilometres from the Albert Edward lake near the Congo state fort of Mbeni the river flows between high banks and is too deep and swift to be forded.[4]

A little lower down it plunges into the Congo forest and its course is not accurately known for the next 65 kilometres; here Stuhlmann crossed it in latitude 0° 47′ N at a point due north of the Ruwenzori range and found it at the beginning of July 1891 to be 60 to 80 metres wide, 1 to 1·5 metres deep and with a strong current,

[1] Report on the Upper Nile, p. 68, 70.
[2] Loc. cit., p. 282.
[3] Stanley. "In Darkest Africa," II, p. 264.
[4] Johnston. "The Uganda Protectorate." London, 1902, p. 194.

flowing in a bed cut one metre deep in clay at one place while at another point further downstream it had cut through a 30 metres cliff of laterite.

Stanley[1] on May 14, 1889, crossed it at a point further downstream in lat. 0° 54′ N. where it was 55 metres wide with a 4-5 knot (2 metres per second) current; a little lower down it was 90 metres wide and a fine deep river. A point some 6 kilometres downstream had been examined 2 days before, and there the river was 70–80 metres wide, swift and deep with banks 3 to 6 metres high, and passable only in canoes.

Moore also marched along the lower part of the river from this point to the lake but gives no information about it in his book. From this ferry to the Albert Lake, a distance of about 50 kilometres, there is a wide low-lying plain at times partially flooded and covered in May with a thin grass some 50 centimetres high.

From these data it would appear that in the dry seasons July to September and January to March, the river does not carry any great amount of water, the amount taken up by the dense vegetation nearly equalling what the tributary streams bring in. In the rainy seasons its volume is greatly increased, and from the flood-marks at the point where the discharge was measured near the Albert lake plain, a probable flood volume of 700 cubic metres per second is deduced.[2] The altitudes of Albert Edward and Albert lakes as at present accepted, namely 965 metres and 700 metres[3] above the sea, give for the Semliki an average slope about 1 in 1000 or 1 metre per kilometre; the upper reaches, and the last 50 kilometres of the river have certainly a very moderate slope, so that in the middle 150 to 200 kilometres there must be a greatly increased slope due to ridges of hard rocks forming a sill or a series of sills across its course.

All descriptious of the descent from the plateau at Fort Portal to the Semliki valley[4] dwell on the rapid fall of the ground which in three main steps of about 400, 150 and 250 metres descends from the altitude of 1530 metres to 730 metres above sea level. It appears therefore

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[1] In Darkest Africa, II, p. 236.

[2] Report on the Upper Nile, p. 71.

[3] This latter value is from hypsometric observations by Mr. J. I. Craig in March 1903 computed with the aid of the barometric observations taken simultaneously at Entebbe.

The values thus determined were :—

Hoima...	1179 metres	Nile, Wadelai	702 metres
Butiaba flagstaff ...	845 „	„ Nimule	698 „
Lake Albert	704 „	„ Asua junction ...	685 „
		„ Fort Berkeley ...	666 „

[4] Report on the Upper Nile, p. 58, and Geog. Jour. Sept. 1904 p. 256.

not improbable that the rocks which have resisted erosion sufficiently to form this lowest step are those which may form the present rapids and falls of the Semliki and may have formed that rock mass which in earlier times retained the waters of the Albert Edward lake, which then poured its surplus water over a fall into the Albert lake below.

The northern half of the Semliki valley is filled with clay sand, and rolled boulders, and into these bedded deposits the river has cut its deep channel. In the southern half nothing of this sort appears; there low hills lie east and west of it some of which, as an elevated block formed once a transverse ridge or barrier across the valley at the time when the Albert Edward Lake was thus maintained at a higher level. Over this flowed the outflow of the lake which gradually cut its way back and lowered the lake. This seems to have been rather below where Stuhlmann first crossed it and where, he says, granite hills lie in the valley with the river winding between them.[1]

From the description of the sharply marked beach lines surrounding the Albert Edward lake it would seem that earth movements may have assisted the erosion of the bar and produced a comparatively rapid lowering so as only to leave marked beach lines at intervals.

The Albert Lake. — In the Albert lake the drainage of the lake plateau collects, and from it the Bahr el Jebel carries it northward to the Sudan and Egypt. Discovered in 1864 by Sir Samuel Baker who greatly overestimated its area, its actual limits were determined by Gessi Pasha,[2] and Mason Bey who circumnavigated it, but no accurate survey of its shores yet exists, although Stanley,[3] Jephson,[4] Emin,[5] Junker,[6] Stuhlmann,[7] Grogan,[8] and others have traversed parts of of it from time to time. It lies between the walls of the western rift valley at an altitude of about 704 metres above sea level[9] and is about 160 kilometres long by 30 to 45 broad; its catchment basin including the area of the Semliki river valley is about 32,000 square kilometres.

At the south end of the lake the shore is low and formed by the deltas of the Semliki and Misisi rivers, which spread into the lake as vast swamps of papyrus reeds and ambatch.

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1 "Mit Emin Pascha ins Herz von Afrika," Berlin 1894, p. 282 and 298.
2 Bull. Soc. Geog., Paris, June, 1875.
3 "In Darkest Africa," vol. II. ch. XXV.
4 "Emin Pasha," London, 1890.
5 "Emin Pasha in Central Africa." Felkin, London, 1888.
6 "Travels in Africa," London, 1892, vol. III, Chap. XIII.
7 Loc. cit. p, 576.
8 "From the Cape to Cairo," London, 1900,
9 Craig. See footnote on p. 71.

From the very moderate area of its catchment basin and the absence of large rivers, except the Semliki and the Victoria Nile, the Albert lake has but a small margin to spare for raising its water level. The rainfall at Butiaba on the eastern shore was 965 mm. in 1904 but this is probably below the total of an average year; on the opposite shore where the south-easterly winds have to rise to the Congo plateau it is probably heavier still.

The gauge at Butiaba, the port for Hoima on the east coast of the Albert lake was established on February 19, 1904, and its variations repeat those of the Wadelai gauge but with a reduced range (Plate V*a*, V*b*.). The level has remained fairly steady throughout 1904, rising slowly towards the end of this year but in the previous year by the end of October it had risen 0·83 metre above its level in March 1903,[1] while the Wadelai gauge had risen 1·17 metre. Thus the difference of range due to the slope from the lake to Wadelai is considerably reduced as the lake rises while as the lake falls it is re-established.

Though the short series of observations available is insufficient to decide finally the relative importance of the summer and winter rains, still the gauge readings seem to indicate that it is the latter which have the greater effect in raising the level of the Albert lake just as is the case for lake Victoria. Using the Wadelai records before the Butiaba gauge was established the gauge readings of the last three years show that the Albert lake was very low in 1902 as compared with the followings years, but rose steadily after August; after the December maximum it fell and then rose rapidly after August, while in 1904 the level was consistently high. Thus the mean lake level for the year will be seen to rise and fall in the same way as the Victoria lake, as is to be expected; 1902 was a year of very low level on both lakes, but in 1903 they rose rapidly being high after June, and this level was maintained throughout 1904 thus giving an increased mean value for this year. We see there fore a very marked variation of lake-level produced by an increase of rainfall in 1903.

The volume discharged at Wadelai, 64 kilometres from the Albert Lake,was measured on 22nd March 1903.[2]

Width	147 m.	Sectional area	770·9 m^2
Mean depth ...	5·28 m.	mean velocity	0·838 m. p. sec.
Max. depth ...	9·52 m.	discharge	646 m^3. p. sec.

[1] Report on Upper Nile, p. 81, footnote

[2] Report on the Upper Nile, p. 94.

A discharge table for the gauge at this point has been computed by Mr. Craig[1] on the basis of this discharge, (see p. 91) from which the mean volume discharged may be approximately derived. (Plate X.).

For a section of the river at this point, see Plate VIII.

WADELAI.

MEAN GAUGE READINGS AND VOLUME DISCHARGED AS DEDUCED FROM THEM.

DATE	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	YEAR
						Mean gauge readings in metres							
1902	0·44	0·26	0·20	0·10	0·18	0·11	0·14	0·24	0·37	0·49	0·76	0·85	0·35
1903	0·75	0·65	0·56	0·51	0·59	0·77	0·98	1·12	1·32	1·63	1·84	1·92	1·05
1904	1·90	1·80	1·69	1·72	1·74	[1·74]	1·74	1·90	1·86	1·90	1·98	1·98	1·82
						Mean discharge in cubic metres per second							
1902	622	577	570	549	568	551	558	578	606	633	692	715	..
1903	692	668	648	637	655	696	744	778	827	904	951	979	..
1904	974	948	919	927	932	932	932	974	951	974	995	995	..

As from May 1904 to March 22 1905 the connection of the gauge well at Wadelai with the river was sanded up, the readings after May 1904 are too low so that the volume actually discharged after that month was larger, but the table makes sufficiently clear how largely the height of the Albert lake affects the volume supplied to the Bahr-el-Jebel. Taking the constant supply furnished by the Victoria Nile above Foweira as about 550 cubic metres per second, hardly any additional water was supplied by the Albert lake and the Nile tributaries below Foweira, in June 1902, while at the end of 1903 and throughout 1904 the addition was not far from 100%.

Felkin[2] when on the lake in December 1878 considered that at Magungo, at the mouth of the Victoria Nile, water was flowing from the Victoria Nile towards the Bahr el Jebel and a second current flowing south-west into the lake. At this time the level of the Albert lake like that of the Victoria lake must have been high after the very heavy summer and autumn rains of that year so that far from drawing upon the Victoria Nile supply the lake was doubtless supplying as much again to the Bahr el Jebel. Any current flowing from the north-east was probably caused by wind which at that season would be northerly.

[1] See p. 90.
[2] "Uganda and the Egyptian Sudan." London, 1882.

The regulating action of the Albert lake smooths out rapid rises and falls of the Victoria Nile which the floods of the tributary streams from the hills of the Acholi district would otherwise cause, and the lake gauge at Butiaba and the Bahr el Jebel gauge at Wadelai consequently rise and fall evenly. The hypothesis recently advanced [1] that the flood waters of the Victoria Nile are here delayed nearly 5 months in their passage down the Bahr el Jebel, is based on a misapprehension of the climatic conditions, and consequently the difference of 5 months between the dates of the maximum gauge readings on the Victoria lake and the maximum readings at Butiaba and Wadelai has been taken to mean that this amount of delay occurs. First it may be remarked that the minima of the gauges at Butiaba and Wadelai occur in the month of March, while at Jinja the Victoria lake is low then and will ordinarily rise considerably before June when it is generally at its maximum. With the March-June rains all three gauges rise but in July-September the Victoria lake falls rapidly in consequence of evaporation by the south-east trade winds and want of the rain in the dry season. The Albert lake on the other hand is still receiving a good supply from the Semliki river and the rainfall at Fort Portal is heavy; the Victoria Nile owes its flood to the rainfall of the Acholi hills, where rain is now heavy, and this supply is poured into the lake, while at Wadelai more than 100 mm. a month of rain is falling. After this date the rain belt is returning south and rainfall increasses in October and November (see p. 84) so that it is not to be wondered at that the maximum reading is reached in December.

Change of level.—The variations in the level of the lake will follow generally those of lake Victoria and the other equatorial lakes, falling in years of deficient rainfall, and reaching in a year of heavy rain, a high level which may be maintained for several years if their rains are up to the average or only slightly in excess. Emin Pasha [2] states that there was an island 2 metres above the lake surface south-south-east of Mahagi where in 1879 there was none. Stuhlmann [3] in 1891 mentions two promontories on the western shore which were islands when Stanley visited the spot in 1889.

Emin Pasha records a shoal at Tunguru in 1876, which in 1880 was a sand bank; Jephson calls it an island in 1886 and in April 1888 it was joined to the shore by a strip of land 1·5 metre above the water-level.

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[1] Willcocks. "The Nile in 1904." London, 1904, p. 30.
[2] Emin Pasha in Central Africa. London, 1888, p. 167.
[3] "Mit Emin Pascha ins Herz von Afrika." p. 582.

In both Albert and Albert Edward lakes there is moreover a large amount of detritus being annually deposited in the lakes, since most of the rivers which fall into them have steep slopes especially on the western shores. Much of this material must be coarse and therefore is soon deposited in the lake so that the growth of some of these islands is probably assisted by deposition as well as by variation of the lake level.

At the southern end where the Semliki and Misisi enter, these rivers have traversed their level flood plains for some distance and the deposit in the lake is fine silt. At the northern end the Victoria Nile is forming a delta with the material which it receives below Foweira as already mentioned.

The obliteration of the Albert Edward and Albert lakes in course of time by the detritus brought down by their tributary streams has been anticipated,[1] and though when this takes place many other changes will doubtless have occurred and the whole regimen of the Upper Nile may have altered, still, as a case of river development, it is interesting to trace the effect which such silting up of the lake basins would have on the Bahr el Jebel. The Ruchuru would traverse the site of the Albert Edward, forming banks from the silt that it carries in flood, with lagoons and marshes behind them; joined by the streams from the east of Ruwenzori their combined waters would flow down the Semliki valley and across the present Albert lake. This is a distance of about 350 to 400 kilometres and the fall is about 250 metres giving sufficient velocity to carry silt to form natural banks. The position will then be that there will be an April-May and a November-December flood corresponding with the rainy seasons, while the present loss from evaporation will be immensely reduced in consequence of the great reduction of water surface.

Summary.—In this most southern part of the Nile basin we have a plateau lying some 1500 metres above sea level and composed of gneiss quartzite and schists; the central portion is occupied by lake Victoria, while the deep fault valley, in which lakes Albert Edward and Albert lie, forms the western portion. Much movement has taken place comparatively recently and blocks of the plateau have been raised, lowered, or tilted, so that the drainage follows the depressions so formed. As yet the rivers have not had time to deposit or erode sufficiently to give a regular grade to their beds so that marshes and

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[1] A Report on the Upper Nile, p. 9.

water-logged depressions still alternate with reaches in which the fall is considerable and the flow therefore rapid.[1] The principal rainy seasons furnish the supply of the lakes and the surplus flows off at the Ripon falls and at the north of the Albert Lake. Owing to the wide expanse of marsh and shallow lake which intervenes between the upper and lower portions of the Victoria Nile, the fluctuations in the level of the Victoria lake have no effect upon the volume of water passing Foweira, which must be a constant amount of about 550 cubic metres per second.

Below this in the rainy season there is an addition, perhaps considerable, from the Acholi hills but no data are available. The effective supply contributed by the lake plateau to the Nile is that which enters the head of the Bahr el Jebel from the Albert lake, and this ranges apparently from about 500 cubic metres per second when the lake is very low to double that amount when it is high. That is, there is a constant supply of 550 cubic metres per second representing the contribution of the Victoria lake, to which the Albert lake may add as much again, or possibly even withdraw some from it; it is the level of this latter lake therefore which is the dominant factor in the hydrography of the lake plateau.

1 Cf. the description of the Oregon district in the 4th annual report of the United States Geological Survey for somewhat similar conditions, except that there the climate is a dry one.

CHAPTER III.

The Bahr el Jebel, Bahr el Zaraf and Bahr el Ghazal.

The basin of the Bahr el Jebel is of small extent, comprising some 190,700 square kilometres including the area drained by the Bahr el Zaraf; it is bounded on the west approximately by the 30th meridian east of Greenwich, while on the east the boundary between it and the Sobat basin lies to the east of the Bahr el Zaraf, between this river and the Khor Filus, to about the latitude of Bor whence it turns south-east so as to include the Latuka hills and the other ranges lying to the east.

This part of the watershed, between the Bahr el Jebel and the Bahr el Zaraf on the west and the Sobat basin on the east, is very ill-defined, for the flat open plains which occur here have no pronounced lines of drainage but are flooded swamps in the rainy season, most of the water evaporating later, though a small proportion is probably drained off by such channels as the Pibor and the Khor Filus. The plateau of the Musha[1] country which lies at an altitude of about 1500 metres above sea level seems here to mark the division between the western and eastern drainage and thence by the Karamojo plateau as far as mount Dabasien the line runs southwards, after which it turns westwards between the Asua river and the Victoria Nile to the head of the Albert Lake.

North of lat. 5° N. the basin consists of almost level plains sloping very gently towards the north and composed of a sandy ferruginous soil derived from the decomposition of the gneiss which is the predominating type of rock in this part and which appears here and there as low round-topped hills, near the foot of the southern plateau.

Between the river valleys the land rises slightly forming a dry ridge of higher land which is in marked contrast to the swamps which occupy the valleys and form a broad belt joining the northern flood plains of the Bahr el Ghazal and the Bahr el Jebel where they unite to form the White Nile. To the south of the fifth parallel the country is of a totally different character; the Bahr el Jebel itself flows in a narrow channel between high hills and its course is interrupted by numerous falls and rapids; on the west the hilly watershed gives rise to streams which flow through densely wooded valleys till on reaching the flat northern plain they disappear in swamps. A most picturesque country lies

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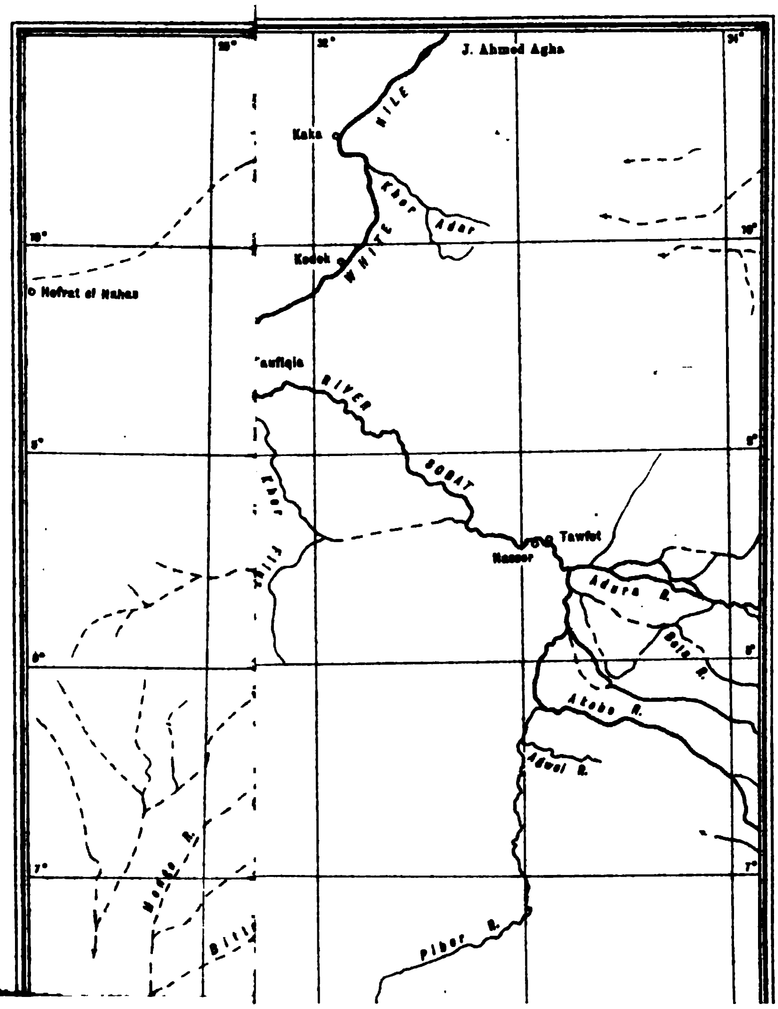
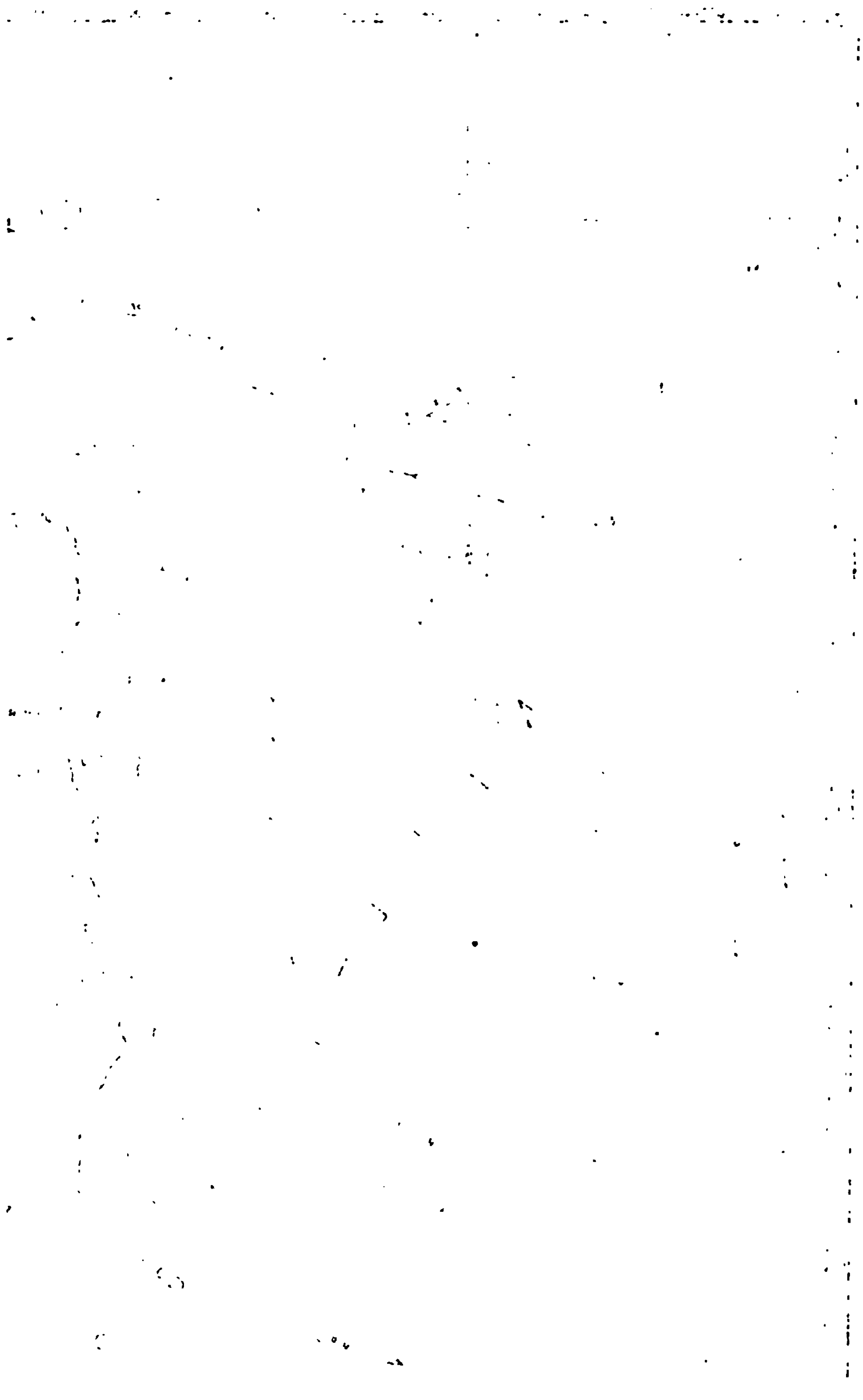
1 Donaldson Smith, Geog. Journ., Dec., 1900.



[1] For detailed description see Report on the Upper Nile, p. 91.



1 Donaldson Smith, Geog. Journ., Dec., 1900.

to the eastward where the spurs, hills and outlying ridges of the great Central African plateau rise to heights of 2500 metres and in some cases even more, in which rise streams, some of which turn to the south and west to join the Asua, while others flow northwards and finally lose themselves in the plains east of Bor which in the rains become swamps and flooded depressions.

The structure of this area is but little known since the hilly parts where it can best be studied are still among the least explored parts of the Nile Basin. From Emin Pasha's descriptions of the Latuka and other hills east of the Bahr el Jebel they seem to consist principally of granitoid gneiss with occurrences of crystalline schists and by the parallelism of the ranges it would appear that the same systems of faulting occur here as have been described in the previous chapter; the NW. to SE. direction is especially well marked. From the decomposition of this granitoid gneiss a sandy laterite has been formed and its red ferruginous character is noticeable in the surface deposits almost everywhere in the southern part of the basin. In the northern part rivers have laid down a gently sloping flood plain of their finer sediment where there are swampy depressions in the midst of vast arid plains in the dry season, while during the rains a great part of the area is under water.

As a result of this structure we find in the southern portion steep slopes, and torrents with rocky beds, which rise in flood after a few hours rain and then quickly fall, while sluggish streams flowing at a nearly constant level, and swamps filled with reeds, grass and papyrus occupy the valleys of the northern part.

In about lat. 2° 12′ N. the Bahr el Jebel leaves the Albert Lake (700 metres) at a point which adjoins the mouth of the Victoria Nile, and from here to the mouth of the Sobat River, a distance of 1280 kilometres, presents two distinct types, the one, a river of low slope and feeble velocity, the other, reaches of rocky bed with numerous rapids, where navigation is impossible.

At the point where the Bahr el Jebel[1] leaves the Albert lake it is really an arm of the lake and continues to be of this character for some distance; indeed for the 216 kilometres from the Albert lake to Nimule the river has the same character, flowing with a feeble velocity except where the channel is narrowed as at Wadelai, at times opening out into lake-like reaches from one to five kilometres wide. The depth is usually from 4 to 6 metres. The mountains which formed the western

[1] For detailed description see Report on the Upper Nile, p. 91.

shore of the Albert lake fall back from the line of the river, and the watershed between the Nile and Congo basins is some 60 kilometres to the west; this ridge sends off as a branch to the north-east a plateau of high land which terminates in Jebel Otze (1650 metres) close to Nimule. On the right bank lies a hilly country much cut up by streams and rivers, where the general altitude of the main ridges is about 1200-1300 metres; these main ridges run in two principal directions approximately NE. to SW. and NW. to SE. and a similar arrangement may be noticed in the reaches of the Bahr el Jebel and in the tributary streams. These directions have already been mentioned as predominant on the northern shore of lake Victoria and doubtless are due to the main direction along which movements of elevation or folding have taken place at some period, or intrusions of harder rocks have occurred, so that unequal erosion has left in relief ridges which now separate the stream basins. No geological study of this region has yet furnished proofs of this, though 10 kilometres to the south of Gondokoro compact black dolerite dykes cross the country cutting through a well-banded quartz-biotite gneiss[1] from SW. to NE. and forming ridges where the rock of the dykes weathers to irregular blocks like the ruins of rubble walls, while the depressions are filled with a sandy clay over which streams flow in the rains, and where swamps lie in the drier season.

Throughout this lake reach the tributaries, few and unimportant, come in on the right bank, except a few khors which drain from the western hills; the principal ones are the Achwa and the Umi near Wadelai and the Tete opposite Dufile.

The altitude of Nimule has usually been taken as 610 metres above the sea which would give a difference of level between this point and lake Albert of 90 metres corresponding to a slope of 1 in 2300 which is much steeper than can be the case for these wide slowly flowing reaches. It appears probable that about 685 metres would be nearer the true altitude.[2]

From this point the river changes its character, turning to the north-west and after flowing for about 80 kilometres to the north reaching Gondokoro at 395 kilometres from the lake and 180 from Nimule. This distance is occupied by a series of cataracts and rapids over which the river rushes usually in a narrrow channel. The principal rapids are those of Fola, Yerbora, Gugi, Makedo and Beden;[3] soon after the last of these the river as a fine stream, 400 to 500 metres wide, and

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[1] Determined by Dr. W. F. Hume.
[2] See p. 71 footnote.
[3] For detailed description see Report on Upper Nile, p. 98-107.

flowing strongly, enters the plain tract and meanders with rapidly diminishing volume through its valley to Lake No where it meets the Bahr el Ghazal to form the White Nile. After Gondokoro there are no more rapids since the river flows through an alluvial plain ; and this long reach of rapids to the south is due to the river descending from the plateau formed by the gneiss and other rocks to the lower alluvial flood plains on the north. The country to the east of this part of the river may be described as a plateau some 900 metres above sea level which slopes northward at first gently, then more steeply as the hill spurs merge themselves in the level plains east of Gondokoro. The central hill mass is that of Agoro which extends some 70 kilometres from south-east to north-west and 40 kilometres from south-west to north-east; it is situated 80 kilometres east of Nimule and has a general altitude of 2100 metres while the principal peak exceeds 3000 metres. Further east other hills Egadang and Harogo 2800 metres, Lonvili 2500 metres, Nangani 2200 metres, the Karamojo plateau and many others stand as witnesses of the former extension of the Central African plateau of crystalline rocks[1] which has been cut up into detached masses by stream erosion, and whose materials are now spread far and wide over the plains to the north. The same SE. to NW. direction is seen among the valleys and spurs as occurred further south. The distanoe of the higher parts of the hills from the river gives moderately long courses to the different tributaries which come in on the right bank but they rise at a considerable altitude and having a steep slope many of them furnish a large supply of water in the rainy season ; the principal of these are the Asua and the Atappi, the Umi, the Karpetu, and the Kit or Gumuru, so that to these the flood of the Bahr el Jebel is due, and the rapid variations in the water level at Gondokoro are caused by the rise and fall of these streams.

On the west side of the river the hills rise steeply to a height of 1200 metres, so that with the exception of one stream, the Khor Ayu which has cut its way through from the west near Labore, the streams have but a short course and doubtless carry a small volume. Behind this ridge the country for about 150 kilometres is unexplored but from the way the streams to the north and west of it flow, it must be a high plateau probably some 1500 to 1600 metres above the sea crowned with higher summits ; it is, in fact, a detached portion of the eastern plateau through which the Nile has cut its way probably following a line of faulting. On the western side of this plateau the river Yei takes its rise, and flowing north finally empties what is left of its waters, after

[1] Macdonald, Geog. Jour., August, 1899, p. 144 and I. D. W. O. Map. No. 1429.

passing through its own marshes, into the valley of the Bahr el Jebel near Ghaba Shambe.

Since in this upper 400 kilometres the Bahr el Jebel traverses that part of its basin which supplies the river, in distinction from the remaining 700 kilometres, in which some 50 cent. of the volume which passes Gondokoro is lost by evaporation and absorption in the swamps, it will be convenient to treat this portion separately from the northern part, the more so as the climatic conditions of the two districts are fairly distinct.

Southern portion of the Bahr el Jebel.—The climate of the southern part of the basin is well represented by the observations taken at five stations, all of which are situated on the river:—

Place	Period
Mongalla ...	Commenced April 1903.
Lado	Observations recorded for 1 year and 7 months only.
Gondokoro...	Mean November 1903, Maximum January 1901, Minimum May 1904, Humidity November 1903.
Nimule ...	Commenced January 1904.
Wadelai ...	„ November 1901.

The mean values up to December 1904 are given in the following tables, which though they are derived from a few years only, are probably accurate to within a small amount since the differences between the hottest and coolest months is but 5°, and the daily range for the greater part of the year does not exceed 13° C.

MEAN TEMPERATURE (CENTIGRADE).

PLACE	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	YEAR
Mongalla ..	27·8	26·5	25·8	26·5	26·0	25·6	24·7	24·8	26·8	26·1	27·2	27·0	26·2
Lado	28·1	29·2	30·0	28·9	27·4	26·2	25·5	25·2	25·3	25·6	26·1	27·0	27·0
Gondokoro..	28·1	26·7	26·1	25·3	25·8	25·4	24·1	23·7	26·4	26·4	27·0	27·0	26·0
Nimule .	27·8	28·2	24·4	24·3	24·5	24·0	23·6	23·4	23·5	22·3	22·2	22·8	24·2
Wadelai ..	27·0	27·6	26·6	26·0	25·8	25·4	25·1	23·8	24·6	25·4	26·2	26·5	25·8

MEAN MAXIMUM TEMPERATURE.

PLACE	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	YEAR
Mongalla ..	37·7	35·5	32·4	30·4	30·4	31·3	30·1	30·5	33·8	34·0	35·2	37·2	33·2
Gondokoro..	35·9	36·2	35·1	33·7	32·5	32·0	32·1	31·1	33·2	33·6	34·0	34·3	33·6
Nimule 1904	37·7	36·9	34·8	34·3	32·5	31·7	30·1	31·1	33·3	33·4	33·4	33·8	33·6
Wadelai ..	35·0	33·8	32·1	31·8	31·4	31·4	30·3	29·8	31·1	31·6	32·1	33·5	32·0

Mean Minimum Temperature.

Place	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Mongalla .	19·1	20·1	22·4	22·8	22·2	21·0	20·2	20·2	21·3	20·6	20·5	19·4	20·8
Gondokoro	..	..	..	..	24·8	17·1	16·3	19·4	19·9	19·6	20·0	18·1	[19·4]
Nimule ..	17·8	22·3	19·3	17·6	20·4	19·3	18·6	18·6	18·1	18·2	16·8	15·1	18·5
Wadelai ..	19·0	21·3	21·0	20·3	20·3	19·5	19·8	18·7	18·4	19·6	20·2	19·6	19·8

Mean Daily Range.

Place	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Mongalla ..	18·6	15·4	10·0	7·6	8·2	10·3	9·9	10·3	12·5	13·4	14·7	17·8	12·4
Gondokoro..	..	..	..	..	7·7	14·9	15·8	11·7	13·3	14·0	14·0	16·2	..
Nimule ..	19·9	14·6	15·5	16·7	12·1	12·4	11·5	12·5	15·2	15·2	16·6	18·7	15·1
Wadelai ..	16·0	12·5	11·1	11·5	11·1	11·9	10·5	11·1	12·7	12·0	11·9	13·9	12·2

Mean Relative Humidity.

Place	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Mongalla ..	52	57	70	74	79	89	89	91	82	82	73	65	75
Gondokoro 7 a.m.	60	67	84	85	89	86	91	91	86	90	87	76	83
Nimule 7 a.m.	71	66	92	92	91	92	94	96	90	91	90	86	88
Wadelai 7 a.m.	47	57	66	75	74	66	82	76	76	84	82	72	71

Rainfall in Millimetres.

Wadelai. Lat. 2° 45′ N. Long. 29° 4′ E.

Date	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1885	..	..	..	..	..	..	..	128	69	143	63	30	..
1886	68	34	114	43	109	51	112	109	101	76	228	21	1066
1887	39	3	214	83	115	67	55	145	128	128	22	38	1037
1888	3	32	59	116	136	125	147	110	71	301	49	30	1179
1902	..	..	103	140	127	79	97	68	160	212	191	31	[1208]
1903	25	0	119	97	124	201	81	100	125	194	66	10	1142
1904	10	36	118	145	118	59	122	144	60	138	199	18	1167
1905	23	8	49	55	137	30	76	132	98	153	97	0	858
Mean..	28	19	111	97	124	87	99	117	102	168	114	22	1088

Nimule. LAT. 3° 37′ N. LONG. 32° 8′ E.

DATE	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	YEAR
1904	0	0	141	48	24	67	164	98	138	123	127	38	964
1905	5	8	42	56	264	36	81	149	108	194	183	42	1168
Mean..	2	4	92	52	144	52	122	124	123	159	155	40	1068

Gondokoro. LAT. 4° 54′ 15″ N. LONG. 31° 40′ 4″ E.

DATE	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	YEAR
1901	20	4	88	83	161	132	65	98	40	73	114	0	878
1902	0	1	64	106	113	106	131	77	310	219	58	23	1208
1903	0	0	13	92	234	143	259	149	104	164	4	1	1163
1904	1	32	105	79	193	57	102	190	103	119	32	6	1019
1905	1	7	3	45	148	94	104	233	155	147	62	0	999
Mean..	4	9	55	81	170	106	132	149	142	144	54	6	1052

Mongalla. LAT. 5° 11′ 58″ N. LONG. 31° 46′ 42″ E.

DATE	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	YEAR
1903	..	..	..	111	90	219	130	236	89	127	3	0	[1005]
1904	0	21	110	83	130	112	49	154	71	160	11	11	912
1905	5	3	2	143	64	91	38	158	175	139	119	4	941
Mean..	2	12	56	112	95	141	72	183	112	142	44	5	976

Ghaba Shambe. LAT. 7° 6′ 44″ N. LONG. 30° 46′ 31″ E.

DATE	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	YEAR
1903	..	..	..	..	..	..	..	..	88	19	0	0	..
1904	0	2	1	24	102	29	53	112	88	46	3	0	460
1905	0	0	0	12	53	54	120	88	232	68	20	2	649
Mean..	0	1	1	18	78	42	86	100	136	44	8	1	514

MEAN MONTHLY RAINFALL IN MILLIMETRES.

PLACE	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	YEAR
Mongalla ..	2	12	56	112	95	141	72	183	112	142	44	5	976
Lado	0	0	27	136	87	151	218	129	123	57	20	2	950
Gondokoro .	4	9	55	81	170	106	132	149	142	144	54	6	1052
Nimule ..	2	4	92	52	144	52	122	124	123	159	155	40	1068
Wadelai ..	28	19	111	97	124	87	99	117	102	168	114	22	1088

WINDS.—PERCENTAGE FREQUENCY. LADO.[1]

MONTH	Year	N	NE	E	SE	S	SW	W	NW	CALM
January	1880	25	20	32	0	0	0	0	1	22
February	80,84	7	8	16	5	11	6	7	1	37
March	84	1	3	13	11	37	6	16	2	11
April	80,83,84	0	0	6	15	25	10	7	1	36
May..	„	0	0	2	8	27	13	7	1	42
June	80,83	0	0	0	2	20	17	10	1	50
July..	80,83	0	0	4	12	18	9	20	0	37
August	81,82	0	0	4	14	23	12	14	0	33
September	81,82	0	1	11	25	13	9	9	2	30
October	81,82	3	2	15	13	14	4	41	2	46
November	81,82	21	8	12	10	3	0	2	2	42
December	81,82	23	13	16	4	0	0	0	0	44

On the higher part of the eastern plateau the temperature is of course lower and the range greater, while the rainfall is certainly heavier though no observations of any kind exist. The irregular rises of the river at Gondokoro, which commence as early as May, each one lasting for only one or two days as a rule, are due to rain-storms in the eastern hills in the basin of the Asua or the Kit rivers. As the rainy season progresses the rivers rise but throughout the rainy season there are sudden rises and falls of the water level due to the combined effect of rain occuring in heavy storms rather than as long-continued rain, and the high altitude of the sources of the rivers and the comparative shortness of their courses, which cause the flood wave to pass with great rapidity to the main river.

Probably the mean annual rainfall in the hills to the east of the Bahr el Jebel may be estimated as amounting to 1400-1500 mm.

The winds at Lado show the seasonal change from being northerly in the dry season to southerly in the rains, and the same reversal is

[1] Pet. Mitt. Ergh. 93, p. 79.

seen at Mongalla, Gondokoro and Wadelai where the series of observations are shorter, as well as in Junker's observations in the Bahr el Ghazal province.[1]

PERCENTAGE FREQUENCY OF WINDS.
Wadelai 1904 (7 a.m. and 2 p.m.).

MONTH	N	NE	E	SE	S	SW	W	NW	CALM
January .. February ..	no observations								
March	53	31	2	0	2	0	8	0	4
April	42	7	42	0	3	3	0	3	0
May	no observations								
June	observations 1st — 6th all E.								
July	5	0	70	10	5	10	0	0	0
August . ..	8	0	89	0	3	0	0	0	0
September ..	0	0	100	0	0	0	0	0	0
October. ..	0	0	100	0	0	0	0	0	0
November ..	0	0	100	0	0	0	0	0	0
December ..	0	0	100	0	0	0	0	0	0

PERCENTAGE FREQUENCY OF WINDS.
Mongalla, June 1903 — December 1904, 8 a.m., 2 p.m., 8 p.m.

MONTH	N	NE	E	SE	S	SW	W	NW	CALM
January ..	3	0	0	0	0	0	0	0	97
February ..	25	0	9	0	1	0	5	0	60
March	19	0	29	1	38	0	10	0	3
April	2	0	16	3	40	3	5	0	31
May	12	0	20	2	37	0	17	1	11
June	4	3	19	9	34	4	18	0	9
July	17	0	13	10	34	6	10	3	7
August . ..	27	8	8	6	20	6	17	2	6
September ..	17	12	11	5	18	2	12	0	23
October. ..	26	14	6	5	22	6	8	2	11
November ..	28	19	20	2	2	0	1	1	27
December ..	62	24	1	0	0	0	0	0	13

The Wadelai and Mongalla observations cover too short a period to be taken as truly representative and local conditions at the former place may affect the results which show a very marked prevalence of easterly winds. Still the Mongalla observations show an easterly deflection of the wind in the summer months and perhaps this may prove to be due to the distribution of atmospheric pressure to the west and northwest. The weathering of the mortar at the house corners in Lado

[1] Pet. Mitt. Erganzungsheft, 92, 93.

shows that E. and NE. are the most usual directions of the wind in the rainstorms of the rainy season and the same has been reported from Renk, a station on the White Nile.

Hydrography.—As has been said, this upper reach supplies practically all the water of the Bahr el Jebel except the rain that falls in the northern part of the valley, and what may drain into it from the swampy channels of the Yei and one or two other streams. Thus the Albert lake and the few streams which join the Bahr el Jebel above Wadelai furnish from 500 to 1000 cubic metres per second according to the level of the lake, and the discharge varies slowly, the gauge at Wadelai seldom varying as much as 0·25 metre in a month, and usually not more than 0·10 metre. (Plate X.).

At this point the lake completely governs the river level and the fact that at Nimule the river was low in 1898 and continued falling in 1899, 1900 and 1901 [1] shows that the Albert lake was also falling, and thus was acting similarly to the Victoria lake (see Plate VI.).

Below Wadelai however the river has a much more pronounced variability on account of the volume supplied by the Asua river and the other tributaries. Of these the Asua is the most important; it rises in the Dodosi hills in lat. 3° 30′ N. while other tributaries drain from the Karamojo hills on the east and from the south and west sides of the Agoro range to the west, at altitudes of about 1500 to 2000 metres above sea level. This region has May to October rains and, while the eastern tributaries have a considerable length and so furnish a regular supply of water, others, such as the Khor Bagger and the Okomo, are much shorter and steeper in their slope and must vary greatly in the volume they discharge.

Macdonald [2] reached Gule on August 21, 1895 having crossed many of the tributary streams of the Asua near their sources and notes that at this time they were all flowing streams, though those further south were dry, the principal stream the Akingo having near its junction with the Asua a width of 40 to 50 metres with well-defined clay banks. He notes that the western edge of the Karamojo plateau is well watered but the plateau itself is dry; this appears to be about the limit where the two rainy seasons of the lake plateau merge into the single rainy season of the Sudan.

The course of the Asua has not been surveyed so that any estimate

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[1] Delme Radcliffe, Geog. Jour., Nov. 1905, p. 484.
[2] Geog. Jour., Aug., 1899.

of its length is only approximate; by measurements on a recent map[1] the length from the Dodosi hills to its junction with the Bahr el Jebel is about 400 kilometres. It has been crossed at several points; Emin Pasha[2] crossed it near Fatiko about 75 kilometres from the mouth in the autumn of 1880 and found it 40 metres wide, rapid, and more than a metre deep. Close to the village of Odiri some 15 kilometres from the junction with the Nile he found it in 1880[3] 26 metres wide and one metre deep; banks of coarse sand bordered the stream and large boulders were common; the banks were 2 to 3 metres high. Baker[4] describes it as being 110 metres wide 0·75 metre deep with a maximum rise in flood of 4 metres. One of its larger tributaries is the Khor Bagger which Emin describes near the junction as about 12 metres wide, 1·5 metres deep rushing over patches of sand and slabs of mica schist;[5] at another point about 30 kilometres higher up it was in the autumn of 1880 20 metres wide, flowing rapidly about a metre deep with flood marks two metres higher and between banks more than 3 metres high. The Khor Atappi[6] which meets the Asua close to the Bahr el Jebel is also an important tributary being some 12 metres wide and nearly 2 metres deep at a point 15 kilometres up-stream. The Kit or Gumuru which rises on the western slopes of the Agoro range must also bring in a large amount of water.

Thus besides the regular supply which passes down the Bahr-el-Jebel from lake Albert and varies very gradually as shown by the Wadelai gauge, there is the variable supply received from the east bank tributaries during the rainy season. On the belt of high and hilly country between Wadelai and the Karamojo plateau the rainy season consists of a maximum in May and June and another in August and September separated by an intervening period during which the rains moderate to some extent. The mean values of the rainfall are derived from too few years of observations to show this very clearly, but the unanimous testimony of travellers and of those residing at stations in this part of the Bahr el Jebel confirm it; it is also the natural consequence of its geographical position between the lake plateau with two rainy seasons and an intervening dry season in July and August, and one rainy season from June to September. The effect of this is well shown by the readings of the Gondokoro gauge; sharp rises and

[1] I. D. W. O. No. 1429, 1899.
[2] Emin Pasha in Central Africa p. 275.
[3] Loc. cit. p. 263.
[4] Ismailia II, p. 70.
[5] Loc. cit. p. 246.
[6] Loc. cit. p. 255 and 262.

falls record sudden variations in the volume of water passing Gondokoro due to floods coming down the eastern tributaries. These are most numerous in May and June and in August and September, while in July when the rain-storms diminish somewhat, the variations are much less, but the heavy rainfall having replenished all the springs, no considerable decrease in the river volume takes place (see Plate X.).

The volume discharged at Wadelai has been worked out on the basis of a discharge measured on March 23, 1903 [1] while the slope has been deduced from the following considerations by Mr. Craig. Four very concordant hypsometrical observations were made at different stations between the Albert lake and Nimule and reduced by comparison with the readings of the barometer at Entebbe, kindly supplied by Mr. Mahon, Director of the Botanic Gardens there. As the type and section of the river between the lake and Nimule vary little, an assumption of uniform slope has been made, the most probable value of which from the observations is $\frac{1}{27000}$,

The data are:—

Volume discharged	646 cubic metres per second
Sectional area	770 square metres
Hydraulic radius	4·80 metres
And the mean velocity is... ...	0·84 metre per second.

Substituting these numbers in the Kutter's formula we obtain:—

$$62{\cdot}93 = \frac{1/n + 64{\cdot}85}{1 + 29{\cdot}6n}$$

a quadratic equation for n, the positive root of which gives $n = 0{\cdot}02369$; this accords with the value of n given by Kutter for such a river channel. With this value a series of values of C in the formula may be calculated to correspond with different gauge readings, the slope being considered constant. For this assumption there is warrant in the fact that the range of Lake Albert is not much less than that at Wadelai. This being so the chief effect of a high level on Lake Albert will be to extend its limits towards the north so that the portion which may be looked on as being level will be brought nearer Wadelai and the fall distributed over a shorter length. In the absence of further data it appears most reasonable therefore to consider the slope as being independent of the gauge reading.

As the value of the slope obtained above differs materially from that hitherto accepted, the reasons for adopting it may be indicated.

[1] A Report on the Upper Nile, p. 43 and App. IV.

The hypsometrical observations though few in number derive added weight from the fact that they are the first in this region that have been reduced by comparison with simultaneous barometric readings at a station of known height so near as Entebbe distant about 350 kilometres; again the total fall from the Albert lake at Butiaba to Nimule is 13 metres, which is in better agreement with 6 metres, the value deduced by Zöppritz from Emin Pasha's observations, than with the 33 metres given by Hann.

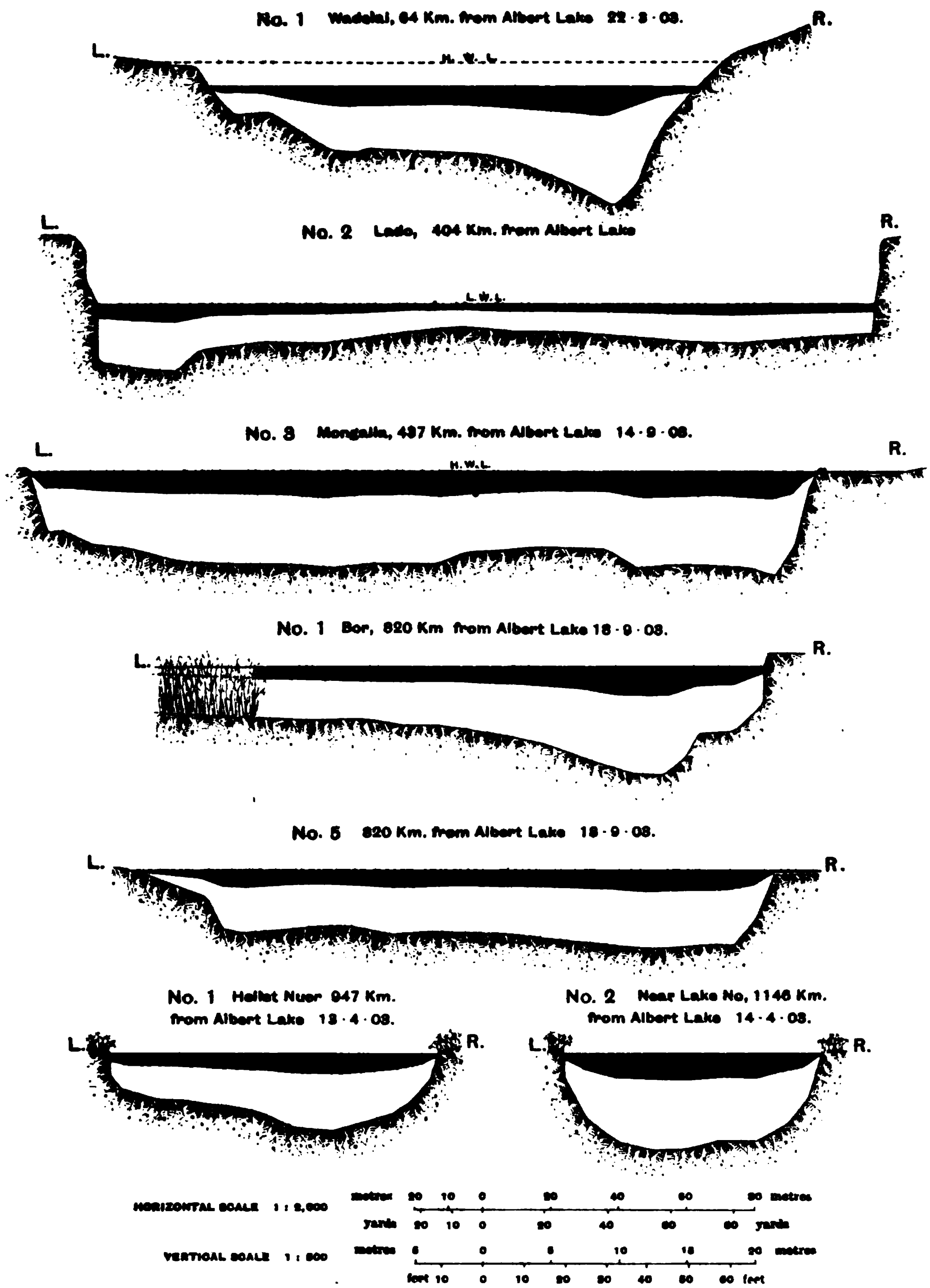
DISCHARGE TABLE FOR WADELAI GAUGE

GAUGE	SECTION	DISCHARGE	GAUGE	SECTION	DISCHARGE
Metres.	Square metres.	Cubic metres per second.	Metres.	Square metres.	Cubic metres per second.
0·05[1]	689·0	538	1·1	859·1	773
0·1	697·1	549	1·2	875·3	797
0·2	713·3	570	1·3	891·5	822
0·3	729·5	591	1·4	907·7	847
0·4	745·7	613	1·5	923·9	871
0·5[2]	761·9	635	1·6	940·1	896
0·6	778·1	657	1·7	956·3	922
0·7	794·3	680	1·8	972·5	948
0·8	810·5	703	1·9	988·7	974
0·9	826·7	726	2·0	1004·9	1000
1·0	842·9	749			

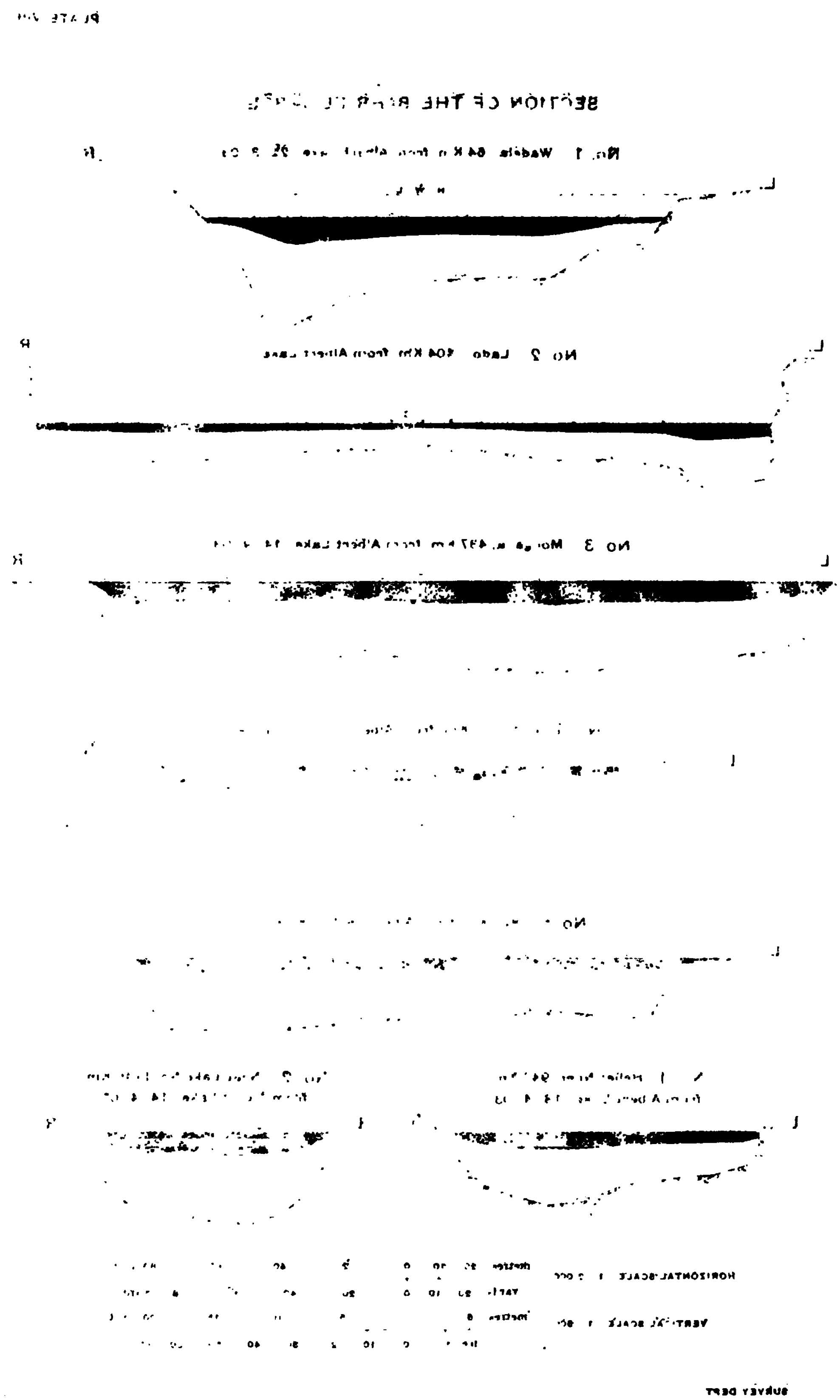
Thus the volume of water passing Wadelai may be said to vary from about 500 to 1000 cubic metres per second, and this amount depends solely on the level of the Albert lake. When it is at a high level, by providing up to double the lowest stage supply, the water-level throughout the valley of the Bahr el Jebel is raised, lagoons fill and extend, and the rainfall of the summer months brought down by the Asua, Atappi, Kit, etc., on the top of such an abundant low stage supply produces extensive flooding which similar rains when the lake was low would be incapable of doing. The lake and its level is then the main controlling factor in the regimen of the Bahr el Jebel valley. It will be seen later (p. 102) that extensive flooding has been recorded in several years in the neighbourhood of Gondokoro and Lado; this has taken place in years of heavier rainfall but the height of the Albert lake is probably a still more important factor. In 1903 the rains in this area were heavy but not sufficiently so to inundate land which

[1] Lowest recorded reading: April 1902.
[2] Mean reading: April 1903.

SECTION OF THE BAHR EL JEBEL



SURVEY DEPT.


SECTION OF THE
No. 1 Wadela 64 Km from Albert Lake
No. 2 Lado 404 Km from Albert Lake
No. 3
HORIZONTAL SCALE
VERTICAL SCALE
SURVEY DEPT

had remained above the flood level for years, had not the Albert lake level been unusually high.

At the Makedo rapids Peney [1] measured the volume discharged on February 27, 1861 and found it to be 565 cubic metres per second. He also measured another at Yerbora rapids which gave from 500 to 600 cubic metres per second.

Northern portion of the Bahr el Jebel.—North of Gondokoro the Bahr el Jebel passes from its mountain tract to its plain tract, and henceforth flows as a meandering stream in the flood plain which occupies the valley. For a short distance north of Lado the ridge of higher land to the west consists of laterite derived by decompositlon from the underlying gneiss, but all the eastern side and the rest of the western side northwards is formed of the sandy materials derived from the plateau to the south and laid down on the flood plains of the rivers which formerly drained this area, with the exception of the four hills which are collectively known as Jebel Zaraf, and one or two similar outliers to the east in the basin of the Sobat.

The constitution of these level flood plains has been described as sandy deposits mixed with coarse peat in places [2] but there seems to be no evidence that anything of the nature of a vegetable deposit exists except the ordinary swamp vegetation which grows in the low ground and in the lagoons which remain after the rains. True peat is out of the question as it is never produced in the tropics except on mountains over 1200 metres in height. [3]

In this old flood plain the Bahr el Jebel has eroded a very shallow valley which it has since partially refilled, while the Bahr el Zaraf has carved out no valley but only the channel that it flows in. To call this valley of Bahr of Jebel a delta, completely formed as far as Bor and in an embryonic stage between this point and lake No [4] is a misuse of the term, since a delta is formed when a stream delivers its load of detritus into a body of still water such as a sea or lake. This description of the Bahr el Jebel is doubtless a consequence of the assumption that the marshes occupy the site of an ancient lake, but the objections to this hypothesis are given later (p. 141). The Bahr el Jebel flows down its valley with a very low slope probably about 1 in 24,000 as a mean

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[1] Bull. Soc. Geog., July 1863, and 1862, p. 249, and Lombardini, "Essai sur l'Hydrologie du Nil," p. 39.
[2] Willcocks. "The Nile in 1904," p. 21.
[3] Schimper, "Plant Geography," Oxford 1903, p. 382.
[4] "The Nile in 1904," p. 33.

slope from Mongalla to lake No,[1] and all the features which it presents are those characteristic of such low grade streams carrying a small load of silt and situated in a tropical climate.

The length of the valley of the Bahr el Jebel from Gondokoro to lake No is about the same as that of the Nile valley from Esna to Cairo, and if Plate XI be compared with a map of Egypt on the same scale, such as that published by Bartholomew of Edinburgh, it will be seen that on the whole their respective valleys do not differ greatly in area.

From Gondokoro to Mongalla, a distance of 42 kilometres, the flood plain is from three to four kilometres wide and in it the river from Lado to Mongalla has a secondary channel to the west of the main one; on either side of the valley is the thorn forest through which small streams drain into the marshes of the valley. Throughout this part the ground level in the valley is 1·0 metre to 0·8 metre above the low stage level of the river, while the higher ground, where the forest grows, is from 2 to 4 metres above it, as at Mongalla, Kiro, Lado and Gondokoro. The flood plain is cut up by numerous channels leading in or out of lagoons which represent former bends or reaches of the river, and in these papyrus, reeds, and grasses, flourish, while on it dense reedy grass grows luxuriantly with isolated acacia bushes dotted about. The soil outside the flood plain is a stiff impermeable earth, for a well sunk at Mongalla below the level of the river gave no water.

From Mongalla to Bor, a distance of 140 kilometres, the flood plain is from 5 to 8 kilometres wide and for almost the whole distance the river is divided into two larger channels besides the numerous small cross channels and spills. Shortly above Bor is the large tract of the valley known to early travellers as Chir island, which lies between the eastern and western branches of the river; at present the former is the main stream but, in 1874 when Licut. Watson[2] made his survey the other branch was in use. It was at the north end of this island that von Harnier stayed during the first half of the rainy season in 1861.[3] Below Bor the valley is from 12 to 14 kilometres wide as far as Kenisa, the western side being followed by the Bahr el Jebel while a parallel branch, the Atem, keeps close to the eastern bank.

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[1] Levelling recently carried out gives a fall of 2·6 cm. per kilometre from lake No to Kodok, and the altitude of the latter place is with fair accuracy 389 metres above see level. Levels carried southwards east of the Bahr el Zaraf give a slope of 6 cm. per kilometre, which if increasing somewhat to the south give about 440 metres for the river at Mongalla.

[2] Now Colonel Sir C. Watson.

[3] Pet. Mitt. Erganzungshaft, X., p. 138.

The Atem river is shown on Poncets map of the Bahr el Jebel,[1] At that time the main channel between Bor and Lado was on the west side of the valley so that the branch is shown as leaving the main stream about lat. 5° 30′ N. and rejoining it near Ghaba Shambé represents the present main channel as far as Bor and beyond that the Atem. Poncet calls it a large channel flowing through the Tuiji district passing by Fagak and rejoining the main stream below Ghaba Shambé.[2]

The flood plain at Bor was in March 1903, 0·6 metre above the river level, and the banks, where exposed, of a yellowish quartz sand of moderately fine grain. This height of the flood plain above the river level naturally varies at different seasons of the year being usually topped in flood, and considerable difference exists between the low stages of different years according to the height of the Albert lake and the volume which is consequently passing Wadelai at this time of year, when the supply from tributary streams is almost negligible. In March 1903 the Albert lake was low, and taking Mr. Pordage's estimate of 0·83 metre as the rise of lake between March 1903 and the end of 1903,[3] it must have been about 0·75 metre higher in May 1904 when Sir William Garstin visited the Atem river;[4] the Wadelai gauge shows an increase of 1·10 metres for the same period equivalent to an increased discharge of about 260 cubic metres per second. This considerably raised the water level in the valley in the upper reaches, the amount gradually lessening in the northern reaches.

The Bahr el Jebel itself changes its character greatly in the Bor-Kenisa reach, meandering in short curves which show clear evidence of having been recently modified; a number of them had altered in shape between the survey of the river in 1901 and its revision in 1903. These changes are small and affect the small bends only, the larger ones taking a much longer time to alter as they tend slowly to work down-stream. Below Kenisa as far as Hellet Nuer, 280 kilometres, the river keeps near the western side of the valley, while for the first 120 kilometres of this distance the eastern side is a wide expanse of papyrus and grass-grown swamps, with water channels and lagoons which furnish waterways more or less navigable by native canoes from the valley of the Bahr el Jebel to the flat swampy area from which the Bahr el Zaraf draws its perennial supply of water.[5] This part of the marshes was

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1 "Le Fleuve Blanc," p. 45.
2 Loc. cit.
3 Report on the Basin of the Upper Nile, p. 81.
4 Loc. cit., Appendix VI.
5 The rainfall on this part supplies an additional quantity in summer and early autumn.

passed by Baker[1] in 1871 by cutting a channel into the Bahr el Jebel and by raising the water by means of a dam sufficiently to enable his boats to pass into the river. In 1900 Commandant Henry made his way through these swamps dragging his boats through small side channels some of which were only 1 or 2 metres wide while at times open reaches of water were but 20 centimetres deep with a hard clay bottom.[2] A little below Ghaba Shambe the forest ceases, and the ground which bounds the flood plain proper is covered with coarse grass, acacia bushes, and occasionally a few deleb palms; on the west bank it passes out of sight 60 kilometres below Hellet Nuer and after this point the swamps of the Bahr el Jebel, the Rohl and the Bahr el Ghazal are believed to join. The country between this part of the Bahr el Jebel and the Bahr el Ghazal cannot be wholly marsh except perhaps in the rainy season when its flatness allows of its being inundated for long distances; at other times the swamps follow the water channels which are separated by slightly higher ground. West of lake No for a considerable distance villages and dry land appear on the southern bank in the dry season and here the rise of the water level in flood probably does not exceed 60 or 70 centimetres. Till the limits of the swamps have been actually surveyed any estimate of their area will certainly be in excess of the truth, for seen from the upper deck of a steamer the top of the grass and papyrus will seldom be as much as 5 metres below the observer's eye, and under these conditions the visible horizon, where, from the curvature of the earth, the line of sight meets the grass tops, is only 7 kilometres distant; any expanse of swamps greater than this will appear to the observer illimitable. Outside the flood plain the country presents the savannah type of vegetation, grass and small perennials with but few thorny shrubs, while here and there stands an acacia bush. In the southern parts and especially on the western side where the humidity is higher, and the dry north winds less pronounced, savannah forest and thorn forest replace it but except for small areas near the river the eastern side of the valley seems soon to open out into bare savannah, much of which is flooded by the summer rains and by the water brought down by streams flowing northwards from the Latuka and other hills.

On either side, when once the northerly outliers of the equatorial lake plateau have been passed the country to the north of them is almost flat; on the west it rises slightly to about half way to the next

[1] Ismailia, London, 1895, p. 99.

[2] Bull. Soc. d'études coloniales, Brussels, Sept., Oct., Nov., 1902.

drainage line, towards which the land again falls. As far south as Ghaba Shambe (lat. 7° N.) this strip of country, usually wooded, can be crossed without difficulty, indeed in the dry season of March and April the absence of water is an obstacle, and the same is true of the plains east and north-east of Bor.

The Danish traveller Pruyssenaere gives a brief description of this land on the west of the Bahr el Jebel in which he spent several months in 1860.[1]

On March 7, 1860 he started westwards from Kenisa; the country consisted of grass-covered plains alternating with wooded tracts, while wherever lagoons or swamps occurred in the low ground numerous fishermen's huts were grouped around. At one day's march from the river the wooded region "Gog"[2] began, parts of which were fresh and green, while other parts were dry and brown according to the kind of trees and the elevation of the ground. At Mirach Ghadiak the ground was a red earth, evidently a laterite, the product of the decomposition of some crystalline rock probably gneiss, under warm and humid conditions, and the ground generally was a red or white sandy earth with reddish banks of sandstone. At Mira Afio about half way between the Bahr el Jebel and an eastern branch of the Yei the highest ground was reached and from here it sloped to the west.

In the winter the trees in the "Gog" lose their leaves, the earth is dry and burnt up, the animals leave it as no water is to be found, and seek the rivers and khors at a distance. Still it is not uninhabitable; by means of wells a permanent supply of water is almost everywhere obtainable. In April the first rain showers fall and at once everything begins to sprout, and the ground is covered with grass; a little later they increase and under the heavy rains of August and September tall grasses grow up and ponds fill. The plains east of the Bahr el Jebel seem generally to lie lower than on the west, for between the Bahr el Jebel and the Sobat there are only acacia woods with the dom and deleb palms, between which lie the depressions which in summer are flooded and in winter dry up. From Khor Gondolek some 15 kilometres east of Agorbar (lat. 6° 38′ N.), the wood falls back more and more from the river, and further north towards the Sobat lie vast almost woodless plains.[3]

These eastern plains have been but little visited and the descriptions of them are meagre. Emin Pasha when the Bahr el Jebel was blocked

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[1] Pet. Mitt. Erganzungsheft, 50, 51, 1877.

[2] This wooded area occupies the higher ground between the Bahr el Jebel and the Yei from 7½° N. lat. southwards; cf. Pruyssenaere loc. cit., p. 13.

[3] Pruyssenaere; loc. cit.

with sadd sent post messengers from Bor to the mouth of the Sobat, who traversed these higher plains and left the swamps of the Zaraf to the north and west, while the Syrian trader Ibrahim Bas, as quoted by Heuglin,[1] crossed them, and appparently reached the Pibor.

Recently Major Liddell R. E.[2] marched through them in March from the mouth of the Sobat to lat 7° N. He mentions that the country had been flooded to an unusual extent; his route was to the east of the marshes (see p. 120).

The tributaries of the Bahr el Jebel are few and only those which join it south of Gondokoro ever reach the river channel. The rest lose their water in the swamps formed by the junction of their marshes with those which occupy the valley of the Bahr el Jebel.

Climate.—The climate of this part of the Bahr el Jebel may be accurately deduced from the observations at Mongalla, Lado, and Gondokoro at the south end of it and Doleib Hilla at the north end The highest temperature is reached in March and April, and the lowest about September in the rainy season. The winds are northerly from November to March and southerly from May to September, being variable in April and October.

Mongalla and Doleib Hilla may be taken as fairly representing the winds of the north and south portions of the Bahr el Jebel while the following table gives the percentage frequency of wind direction observed at Ghaba Shambe in 1904 and 1905 at 8 a.m. The prevailing northerly winds from October to March and southerly winds during the summer months are clearly shown; the latter have a marked easterly component as already mentioned.

PERCENTAGE FREQUENCY — GHABA SHAMBE, 1904 AND 1905, (8 a.m.).

MONTH	N	NE	E	SE	S	SW	W	NW	CALM
January ..	16	61	3	3	10	0	0	0	7
February ..	0	86	0	0	3	0	0	0	11
March.. ..	4	33	17	13	4	7	7	2	13
April	2	4	40	23	8	3	2	3	15
May	0	10	8	51	19	2	0	0	10
June	0	5	22	25	23	7	7	0	11
July	0	3	15	27	11	7	11	7	19
August. ..	0	0	23	16	21	6	18	0	16
September ..	3	3	18	28	12	3	7	9	17
October. ..	3	11	21	16	15	3	20	0	11
November ..	6	25	32	15	15	0	2	0	5
December ..	23	71	0	0	0	0	0	0	6

[1] Pet. Mitt. Erganzungsband, II, Part VIII, p. 104. 1862.
[2] Geog. Journ., Dec., 1904, p. 651.

The average rainfall is probably about 800 mm. annually, though the northern part may prove to have a less amount. Observations have been made at Ghaba Shambe since 1904 only and for this year the total was only 460 mm. but this may prove to be exceptional; in any case Pruyssenaere's estimate of over 2500 mm. of rain for this part is excessive.[1]

GHABA SHAMBE RAINFALL IN MILLIMETRES, IN 1904 AND 1905.

Months	1904	1905	Months	1904	1905
January	0	0	July	53	120
February	2	0	August	112	88
March	1	0	September	88	232
April	24	12	October	46	68
May	102	53	November	3	20
June	29	54	December	0	2

Total 1904, 460 mm., 1905, 649 mm.

As observations are so few in this region and as the humidity and evaporation are of special importance in any consideration of the swamps and the part they play in the regimen of the river, it will be useful to include three sets of observations, one made by me in March-April 1901 and the other by Mr. J. I. Craig in August-September 1902; and to compare them with those made by Lieut. Watson R. E. in 1874. The observations for temperature and humidity were made with an Assmann aspiration psychrometer and those for evaporation by means of a Piché pattern evaporimeter. Taken at the driest and wettest times of the year respectively they furnish a fair idea of the range of humidity and evaporation in this area, while those of 1874 cover the months of October and November.

[1] Pet. Mitt. Erganzungsheft 51, p. 27.

METEOROLOGICAL OBSERVATIONS TAKEN ON THE BAHR EL JEBEL 1901 BY CAPTAIN H. G. LYONS.

DATE	TEMPERATURE °C								RELATIVE HUMIDITY %						VAPOUR TENSION in mm.						EVAPORATION in mm.			WIND		REMARKS
	6 h.	8 h.	11 h.	14 h.	17 h.	20 h.	Max.	Min.	6 h.	8 h.	11 h.	14 h.	17 h.	20 h.	6 h.	8 h.	11 h.	14 h.	17 h.	20 h.	Day	Night	24 h.			
17 March.	22·6	27·0	34·0	37·7	34·2	25·0	38·0	23·0	49	32	8	11	24	55	10·1	8·7	3·3	5·5	10·0	13·0	5·3	3·2	8·5	NE	1	Mouth of Sobat.
18 „	18·8	23·8	29·0	34·0	33·4	25·2	38·0	17·5	73	69	29	36	44	80	11·8	15·1	9·0	14·5	17·2	19·2	6·2	0·7	6·9	S	1	Lake No.
19 „	17·2	27·5	31·6	34·2	32·0	24·1	38·0	15·3	84	65	36	12	24	40	12·2	17·7	12·7	4·9	8·4	8·9	6·4	3·4	9·8	E	1	
20 „	21·4	24·4	33·8	36·4	33·0	28·0	36·5	17·0	69	43	3	13	26	50	13·0	9·6	1·3	6·0	9·8	13·8	13·0	1·4	14·4	NE	3	Hellet Nuer.
21 „	20·2	25·4	30·6	35·0	30·2	28·4	37·6	16·7	92	73	42	24	41	82	16·3	17·6	13·7	10·2	13·2	23·5	3·9	1·5	5·4	—	0	
22 „	22·8	27·6	32·8	36·8	33·0	28·8	38·5	21·5	68	65	42	19	59	89	14·0	17·7	15·6	8·8	21·9	26·3	7·5	1·5	9·0	SE	2	Ghaba Shambe.
23 „	24·4	29·6	34·0	..	34·4	32·2	38·6	24·0	79	51	36	..	42	37	17·8	15·7	14·1	..	16·9	13·4	12·9	3·4	16·3	E	2	Kenisa.
24 „	24·8	25·2	22·8	24·2	25·5	24·4	26·1	23·0	68	71	89	83	83	87	15·8	17·0	18·3	18·7	20·1	19·6	2·1	0·5	2·6	SE	1	Rain 2·9mm.
25 „	23·6	25·8	31·5	33·6	32·1	30·4	36·0	21·6	88	78	52	37	47	37	19·0	19·2	17·6	14·4	16·8	12·0	9·8	4·4	13·2	SE	2	
26 „	22·6	27·4	33·6	36·4	..	32·6	38·8	21·7	71	55	31	20	..	39	14·5	14·9	11·8	9·0	..	14·2	9·7	0·7	10·4	SE	2	Kiru.
27 „	23·6	29·8	34·8	37·0	30·4	30·0	38·5	23·0	73	42	27	23	40	50	15·9	13·1	11·1	11·2	13·1	15·9	9·3	1·7	11·0	S	2	Rain at night 38mm.
28 „	23·0	23·5	26·8	..	28·0	27·0	..	22·0	86	81	63	..	62	68	18·0	17·5	16·4	..	17·4	18·0	3·5	2·3	5·8	S	2	Lado shower.
29 „	25·4	27·8	34·4	34·2	33·6	28·6	35·8	22·2	64	60	30	27	32	61	15·4	16·8	12·0	10·7	12·5	17·8	8·4	3·4	11·8	SE	2	Gondokoro shower.
30 „	22·2	25·0	32·8	33·8	31·8	29·0	35·5	21·5	77	77	35	33	44	60	15·4	18·2	13·0	13·1	15·5	18·0	7·7	3·7	11·4	SE	3	Rain 5mm.
31 „	27·0	25·3	24·4	26·8	27·6	25·8	30·8	24·5	68	61	85	64	63	86	18·0	16·6	19·3	16·7	17·3	21·3	2·7	0·6	3·3	N	1	
1 April.	23·6	25·6	28·2	30·6	..	25·6	32·4	22·4	88	80	66	52	..	84	18·9	19·7	18·8	16·8	..	20·4	2·6	0·8	3·4	S	3	Rain 1·5mm.
2 „	22·0	22·5	..	30·3	29·3	27·0	33·0	20·5	86	80	..	43	53	58	16·8	16·2	..	14·0	15·9	15·5	2·8	0·9	3·7	S	2	Lake No.
3 „	23·2	22.8	31·6	33·8	33·6	30·4	..	20·8	81	84	40	26	29	40	17·1	17·4	13·8	9·9	11·4	12·7	3·0	1·8	4·8	SE	2	Rain 2·7mm.
4 „	24·6	27·8	..	28·0	29·6	27·0	31·3	21·0	76	57	..	52	43	61	17·4	15·7	..	14·5	13·2	17·0	5·2	2·6	7·8	SW	2	
5 „	..	25·6	27·8	31·4	33·0	29·8	35·6	23·6	..	70	54	36	31	46	..	17·1	15·0	12·4	11·8	14·2	4·5	2·1	6·6	S	1	
6 „	23·4	27·4	30·0	31·2	..	27·2	33·0	23·0	74	59	40	41	..	69	16·0	16·0	12·6	13·6	..	18·7	7·2	1·8	9·0	—	0	
Means ...	22·8	26·0	30·8	32·9	31·4	27·9	35·4	21·2	76	64	43	35	44	61	15·7	16·1	13·1	11·8	14·6	16·8	6·4	2·0	8·3	—	1·7	

Meteorological Observations taken on the Bahr el Jebel in 1902 at 8 a.m. daily, by Mr J.I. Craig.

Date	Temp. C°.	Relative humidity. %	Vapour tension. mm.	Evaporation mm.	Wind.	Rain mm.	Place
28 August	25·1	79	18·7	3·4	S. light	0	Taufikia.
29 „	24·9	86	20·1	4·7	S. v. light	0	Lolle.
30 „	27·8	67	18·7	4·0	S.E. mod.	0	Zaraf.
31 „	24·4	88	19·8	4·2	S.E. fresh	0	Lake No.
1 Sept.	26·2	73	18·5	4·8	S. v. light	0	..
2 „	23·0	91	19·0	4·7	S. 1	9·3	Hellet Nuer.
3 „	23·0	84	17·6	3·8	S. 2	0	..
4 „	27·6	67	18·4	6·1	S. 1	0	Ghaba Shambe.
5 „	25·3	88	21·2		S. 2	0	Kenisa.
6 „	..	..	..	13·4	N.E. 3	27·8	..
7 „	25·6	82	20·0		S. 1	0	..
8 „	24·6	87	19·9	5·0	S. 2	3·7	Mongalla.
9 „	25·8	81	20·1	2·4	S. 1	1·9	Gondokoro.
10 „	24·0	78	17·4	4·6	S. 2	..	..
11 „	..	..	..	15·4	..	..	..
12 „	..	..	..		..	..	..
13 „	..	..	..		..	..	Mongalla.
14 „	25.8	67	16·6		S. 3	2·1	..
15 „	..	..	..	7·8	..	..	Kiro.
16 „	26.1	92	23·3		S. 3	1·2	..
17 „	..	..	..	13·3	..	..	..
18 „	23.8	91	20·0		S. 1	0	Hellet Nuer.
19 „	26.3	86	21·8	5·9	W. 3	0	..
20 „	25.2	80	19·2	6·1	S.W. 2	3·0	Khor Deleb.
21 „	..	..	..	5·4	..	..	Zaraf.
22 „	27.8	91	25·2	4·7	E. 2	0	..
Mean	25·4	82	19·8	4·6	..	Total 49·0	..

Meteorological Observations taken on the White Nile, in 1874, by Lieut. C. M. Watson R.E.[1]

Place	Date	Temperature in shade 0 cent.			Relative Humidity %			Vapour Tension m/m			Wind		Remarks
		8 a.m.	noon	8 p.m.	8 a.m.	noon	8 p.m.	8 a.m.	noon	8 p.m.	Direction	Force	
Khartoum	Oct. 9	28·3	..	..	56·7	..	..	16·14	..	..	..	..	Fine.
	„ 10	25·0	..	..	61·0	..	..	14·32	..	..	..	..	„
On White Nile.	„ 11	..	..	30·0	..	..	58·4	..	..	18·28	NW	4	Heavy rain at night.
	„ 12	26·9	30·8	31·7	68·4	58·5	..	18·11	19·36	..	NW	3	Fine; rain at night.
	„ 13	28·6	32·5	30·6	65·5	52·0	..	19·15	18·91	.	NW W SW	2 3	Heavy clouds and lightning; a little rain.
	„ 14	28·1	33·9	31·1	65·0	39·9	..	18·32	15·87	..	SW	2	A little rain.
	„ 15	26·1	32·8	29.4	69·6	38·8	..	17·50	14·48	..	WSW	3	Fine.
	„ 16	31·7	33·9	31.7	46·3	42·9	59·1	16·09	16·85	20·63	W	1	Very fine.
	„ 17	31·7	..	27·8	49·9	..	63·0	17·23	..	17·56	SE	4	Cloudy; lightning.
	„ 18	26·1	30·6	28·9	82·0	62·0	63·9	20·69	20·08	18·96	SE	1	Fine.
	„ 19	25·6	32·2	24.4	86·0	53·0	86·8	21·00	19·09	19·65	SE	2	Fine a.m.; heavy rain p.m.
	„ 20	26·1	34·4	25·6	82·0	46·6	69·2	20·69	18·96	16·91	S	5	Fine.
	„ 21	24·4	29·4	24·4	86·8	68·0	86·8	19·65	20·83	19·65	S	3	„
	„ 22	24·4	29·4	25·6	77·9	44·6	81·2	17·64	13·51	19·86	SE	2	„
	„ 23	27·8	31·7	26·1	45·0	46·4	73·9	12·60	16·09	18·60	SE ENE	2 6	Fine; Squall evening. Fine.
	„ 24	..	29·7	25·0	..	66·5	82·0	..	20·64	19·28	S	3	„
	„ 25	25·6	28·9	26·1	81·2	71·5	78·0	19·86	21·13	19·55	S	1	
	Mean	27·09	31·55	27·89	68·2	53·1	72·9	17·93	18·14	18·99	—	2·8	
$\frac{8+12+20}{3}$		28.84			64·7			18·35			—		

[1] Jour. R. Geog. Soc. 1876, p. 424.

Meteorological Observations taken on the White Nile, in 1874, by Lieut. C. M. Watson R.E.—*continued.*

Place	Date	Temperature in shade 0 cent.			Relative Humidity °/₀			Vapour Tension m/m			Wind		Remarks
		8 a.m.	noon	8 p.m.	8 a.m.	noon	8 p.m.	8 a.m.	noon	8 p.m.	Direction	Force	
Solat.	Oct. 26	26·7	30·0	25·6	69·9	58·4	81·2	18·24	18·28	19·86	SE	2	Fine.
	" 27	25·6	30·6	26·7	86·0	62·0	78·0	21·00	20·08	20·32	S SE	3	"
	" 28	..	31·1	26·1	..	62·5	82·0	..	21·00	20·69	SE	2–6	Heavy rain; lightning [p.m.
	" 29	25·6	30·0	23·3	81·2	68·6	86·0	19·86	21·60	18·32	S	5	A little rain.
	" 30	25·6	30·6	26·7	81·2	68·6	81·7	19·86	22·34	21·30	S	2	Fine.
	" 31	25·6	30·0	..	86·0	68·6	..	21·00	21·69	..	SE	4	Cloudy.
	Nov. 1	26·1	30·6	25·6	82·0	62·0	86·0	20·69	20·08	21·00	S	2	Fine.
	" 2	27·8	28·3	27·8	74·4	70·9	74·4	20·62	20·31	20·62	SE	2–3	Cloudy; fine.
On Bahr el Jebel.	" 3	25·0	29·4	27·8	86·0	64·4	70·4	20·23	19·64	19·64	S	2	Fine.
	" 4	28·3	30·0	25·0	70·9	61·4	86·0	20·31	19·26	20·23	SE	4	Threatened rain.
	" 5	26·7	30·6	26·1	78·0	62·0	86·2	20·32	20·08	21·68	S SE	3	Cloudy.
	" 6	25·6	..	22·8	86·0	..	90·4	21·00	..	18·63	NE E	2 4	Very cloudy.
	" 7	24·4	30·6	..	82·0	..	..	18·55	..	..	NE	3	Fine.
	" 8	26·1	30·0	23·9	82·0	61·4	81·7	20·69	19·26	17·95	E SE	2	Fine morning; rain [4 p.m
	" 9	23·9	28·3	23·3	85·6	70·9	86·0	18·86	20·31	18·32	SE	3	Cloudy.
	" 10	25·0	28·9	23·3	82·0	60·3	81·1	19·28	17·82	17·26	SE	2	"
	" 11	25·6	31·1	..	77·8	54·9	..	18·91	18·58	..	SW	2	Fine.
	" 12	26·7	30·0	25·6	62·7	51·8	69.2	16·23	16·20	16·91	SE	4	"
	" 13	25·6	30·6	26·7	81·2	54·5	73.3	19·86	17·91	19·18	S SE	2–3	Very fine.
	" 14	25·0	..	26·7	86·0	..	78.0	20·23	..	20·32	E SE	2–3	Fine.
	Mean	25·84	30·04	25·47	80·0	62·5	80.7	19·78	19·68	19·54	—	2·9	
$\frac{8+12+20}{3}$		27·12			74·4			19·67			—		
Gondokoro	Nov. 15	26·1	..	..	78·0	..	..	19·55	..	..	SE	2	Fine.
	" 16	..	..	..	..	..	..	..	..	..	..	..	"
	" 17	..	..	..	..	..	..	..	..	..	..	..	"
	" 18	..	..	..	..	..	..	..	..	..	..	..	"
	" 19	24·4	30·6	28·3	77·9	..	..	17·64	..	..	NE	3	"
	" 20	28·3	33·9	25·0	60·3	42·9	73·4	17·25	16·85	17·27	E	2	Very fine.
	Mean	26·27	32·25	26·65	72·1	42·9	73·4	18·15	16·85	17·27	—	2·3	
$\frac{8+12+20}{3}$		28.39			62·8			17·42			--		
Oct. 26 to Nov. 20		25·90	30·26	25·59	79·0	61·4	80·3	19·55	19·52	19·42	..	2·8	
$\frac{8+12+20}{3}$		27·25			73·6			19·50			2·8		

Wind Directions Observed.

Date	N	NE	E	SE	S	SW	W	NW	Total
Oct. 9 to 25	..	0·5	0·5	5	4	2·5	2·5	3	18
Oct. 26 to Nov. 20..	..	3·0	4·0	14	7	1·0	..	..	29
Total.. ..	..	3·5	4·5	19	11	3·5	2·5	3	47

For what is usually described as a vast expanse of flooded swamps the humidity as shown in the foregoing tables may seem lower and the

evaporation higher than would be expected, but the swamp area in the dry season is very small compared to the vast steppe and desert area lying to the north and the dry Sobat plains on the east. In the March observations NE. and E. winds and even SE. winds if strong greatly diminish the humidity, producing an average evaporation of 8·3 mm. daily while even in the height of the rainy season it averages 4·3 mm. Schweinfurth[1] puts the yearly evaporation in the valley of the Bahr el Jebel at 1550 mm. or 4·1 mm. per diem, which would seem to be a low estimate. But for this, the flooding of this part of the Sudan would be much greater, for as will be shown later, the volume discharged by the Bahr el Jebel into the White Nile is nearly constant throughout the year, so that evaporation assisted by the rank growth of vegetation has to dispose of not only the 60% of the water which passes Lado, and does not reach lake No, but also the 700 millimetres of rain which falls in the valley of the river annually. If 6 mm. be taken as the average daily evaporation, and this figure does not seem to be unreasonable under the circumstances, the quantity so removed amounts to about 2000 millimetres per annum of which about 700 millimetres is the yearly rainfall. If the length of the valley from Gondokoro to lake No be taken as 500 kilometres and the mean breadth as 10 kilometres, this represents an area of 5000 square kilometres from which 1·3 metres depth of water is evaporated annually, the equivalent of a volume of about 200 cubic metres per second throughout the year, but since the data furnished by the evaporimeter represent only the amount which would be evaporated from an open sheet of water, no account has been taken of what is absorbed by the vegetation and transpired from its leaf surfaces by which means the amount of water removed is very largely increased.

Changes even in recent years have taken place in the upper valley of the Bahr el Jebel; Gondokoro had to be evacuated in 1875 because the eastern river channel there had silted up to a great extent; on the other hand at Lado, 15 kilometres to the north the stream was pressing against the west bank, and to-day it is still eroding there. Marno[2] remarks that in 1881 the east channel at Gondokoro was said to have deepened, and at the present time it is navigable again.

Between Lado and Bor there are many islands and sandbanks which are changing frequently, and for some years before 1881[2] what had been the main channel had become unnavigable and boats followed a

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[1] Pet. Mitt. 1902, p. 189, see also Chap. VII.
[2] Pet. Mitt. 1881, p. 414.

more easterly branch known as the Khor Kir Shambe, which is the main channel to-day, from lat 5° 30′ N. to near Bor. Nearly as far as Bor the eroded material brought down from the mountain tract is coarsely sandy and even in parts a gravel, but nórth of this it is a fine sandy mud containing a large amount of vegetable material and ashes from the burnt vegetation. At Bor sandy layers occur in the bank section alternating with others of mud but north of this the coarser material occurs but rarely.

The following table gives such references to the state of the river in past years as are to be found in the acccounts of different travellers; as a low winter supply means that lake Albert was low, it is interesting to note that this was the case in 1849 to 1853, and again in 1858 when probably the same was true of the other equatorial lakes.

1848 / 1849	Winter; Bahr el Jebel exceptionally low.[1]
1850	January; Bahr el Jebel exceptionally low at Gondokoro.[2]
1853	January; Low water at Gondokoro.[3]
1854	January 0·90 m. higher at Gondokoro than January 1853.[3]
1858	Summer rains feeble.[3]
1859	Water in April very low.[3]
1859	Rains on Bahr el Jebel failed April-June, but later they were very heavy.[4][5]
1861	18th March; Lowest stage of river at Gondokoro;[6] Rains in Bahr el Jebel late, but then very heavy, high flood;[7] Continuous rain at Poncets Zeriba from 20th August to 20th September.[8]
1862	Rains heavy in Bahr el Ghazal and Yei districts.[9]
1863	27th January: Bahr el Abyad low;[10] 7th February, Bahr el Ghazal at Meshra Rek unusually high.[11]
1864	White Nile very low in March compared with 1863.[12]
1868	Rains were feeble in Bahr el Jebel district since wells in country west of it were dry in the following spring.[13]
1871	Very dry in Bahr el Jebel; drought at Gondokoro.[14]

1 Knoblecher: Reise auf dem Weissen Nil. Klun. p. 27, 29.
2 Pet. Mitt. 1859, p. 307.
3 Poncet, "le Fleuve blanc" p. 100, 139.
4 Morlang, "Pet. Mitt. Erganzungsheft," 10.
5 Pruyssenaere, "Pet. Mitt. Erganzungsheft," 50, p. 8.
6 Peney, B.S.G. July 1863.
7 Von Harnier, "Pet. Mitt. Erganzungsheft, XI." p. 140.
8 Poncet, le "Fleuve blanc."
9 Petherick, Travels in Central Africa.
10 Heuglin, "Reise in Gebiet des Weissen Nil," p. 71,
11 Ibid, p. 107.
12 Pet. Mitt. Erganzungsheft 15, p. 18.
13 Poncet. le "Fleuve blanc."
14 Baker, "Ismailia 1." p. 316.

1872 Better season than 1871; high flood at Gondokoro.[1]
1877 July at Gondokoro; no rain, river low.[2]
1878 High flood in Bahr el Jebel; Lado flooded in 1878, still very high at Lado in December,[3] which points to an unusually high level of the Albert lake.
1879 November 1879, river at Lado still high[4] Lado flooded.
1880 Unusual rains in Bahr el Ghazal.[5]
1882 Short of rain at Lado up to July.[6]
1883 Very heavy rain Lado and southwards; Lado flooded and gardens destroyed.[7]

(See Chapter X for a comparison of these date with the Blue Nile flood).

Tributaries of any size are rare north of lat 6° N. and those that join the Bahr el Jebel have their valleys so choked with vegetation that but little water can reach the main stream.

On the left bank is the Khor Lurit 37 to 150 metres wide and 2 metres to 4 metres deep in the dry season which enters the main stream to the north of Lado.

The Khor Lankaja is said to join the valley of the Bahr el Jebel some 75 kilometres below Lado.[8] It rises in the high (610 metres) ground west of Lado, and collects the water of a number of small khors. Khor Koda, one of its branches, was in September 1881 in latitude 5° 4′ N. when crossed by Emin[9] 0·5 metre deep, and 3 metres wide, but when in flood it overflows the land far and wide. The country to the west of it is completely flooded in the rainy season.

There are also several Khors, Ginetti, Khos and Ta which rise in the Latuka highlands and flowing northwards lose themselves in the swamps to the east of the Bahr el Jebel in the neighbourhood of Bor, where they flood the open plains in the rainy season and form swamps during the rest of the year where what remains of their diminished supply evaporates. In latitude 5° 20′ N. on the western side Khor Taffari and Khor Ito are the principal streams which increased by numerous small khors go to make up the river Gel. In September 1881 after a very dry season, Emin Pasha[10] found the Taffari rushing rapidly from south

[1] Ibid II, p. 542.
[2] "Emin Pasha in Central Africa," Felkin, p. 1.
[3] Ibid, p. 98.
[4] Pet. Mitt. 1881, p. 1.
[5] Casati I. p. 66.
[6] Felkin, "Emin Pasha in Central Africa," p. 437.
[7] Felkin loc. cit., p. 453.
[8] Junker and Hassenstein's Map. Pet. Mitt. Erganzungsheft, 92, 93.
[9] "Emin Pasha in Central Africa," p. 302.
[10] Loc. cit., p. 307.

to north, 15–18 metres wide, and 1·5 metres deep. In December of the same year it was dry at this point. The Khor Ito at the same time was about 30 metres wide and 1 to 1·5 metres deep. 15 kilometres further upstream the Ito in December 1881 was 15 metres wide and 1 metre deep, flowing between rocky banks about 3 metres high. Eventually these two khors flow north-east through the Eliab contry and join to form the river Gel which reaches the Bahr el Jebel opposite Bor.

It was crossed in latitude 4° 50′ N. by Peney [1] (though thought by him to be the river Yei), in January 1861, when he describes it as being 80 metres wide, 0·35 metre mean depth, and as having a velocity of 0·33 metre per second, and discharging 9 cubic metres per second.

Felkin and Wilson [2] also crossed its upper branches in about latitude 5° 5′ N. on 20th September 1879 and speak of it as being at times a considerable stream, with banks 6 metres high and with evidences of the river flowing at times bank full.

The Yei is the principal tributary of the Bahr el Jebel and joins it about 50 kilometres north of Ghaba Shambe, but like most other rivers in this country its waters are mostly expended in the marshes which fill its valley in the northern part, so that little if any reaches the main river even in the rainy season. It rises in latitude 3° 30′ N. and flows in a northerly direction throughout the whole of its course.

In November 1877 Junker crossed it [3] in latitude 4° N. and found it a mountain stream 25 metres wide, 1 metre deep, and rushing along a shallow rocky channel.

Junker [4] crossed it on 16th February 1877 at Wandi in latitude 4° 30 N. where it was then 45 metres wide, more than 1·5 metres deep, and with steep banks.

In 1862 at the end of January, Petherick [5] found this river at Wayo in latitude 4° 45′ N. discharging about 16 cubic metres per second and estimates that in flood it would rise to about 72 cubic metres per second. The bed was 117 metres wide, of which some 30 metres were dry and the water level was 0·6 metre below flood height. On 27th September 1879 Felkin and Wilson crossed it at Amadi in latitude 5° 30′ and found it 180 metres wide, 1·5 metres deep, and flowing with a velocity of 0·76 metre per second, giving a discharge of about 220 cubic metres per

1 Bull. Soc. Geog. July 1863, p. 17.
2 Pet. Mitt. 1881, p. 89 and Uganda and the Egyptian Sudan.
3 Travels in Africa, I. p. 451
4 Ibid, p. 282.
5 Petherick, "Travels in Central Afrika" I., London 1869, p. 295.

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second. Below Amadi there are small rapids. At Bufi in latitude 6° N. at a ford, the river was in October 1881, 80 metres wide, and about 1·25 metres deep.

Two surveys of the river, the first made in November 1874,[1] and the second in March 1901[2] and revised in March 1903[3] furnish a means of comparing the course followed by the Bahr el Jebel at these two dates and determining the amount of change in the different reaches durlng 28½ years. (Plate IX).

On comparing the compass survey of 1903 with that of Watson made in November 1874 it may be generally stated that the agreement in the northern reach from Hellet Nuer to Lake No is extremely close even in the smaller curves; in the middle reaches from Bor to Hellet Nuer the correspondence is less complete; for considerable distances corresponding loops and bends can be readily recognised, but at other points the old main channel has been deserted and a new one excavated in a former cross-cut or backwater. Further south between Gondokoro and Bor the river has changed its course since the old main channel is now only navigable in flood, and the eastern branch, Kir Shambe, is now the main channel. The reason of this is clear, since the southern portion is affected by the annual flood of the river and the discharge in September is often double what it is in April, moreover the differences in the supply of different years will also be directly felt, and the channel which suffices for ordinary years will be unable to carry the increased volume in an unusually rainy season, especially if the Albert lake is also high; the river will therefore erode, modify and alter its bed to meet varying conditions. Thus it is that in comparing the line of the river in the map of November 1874 with that of March 1903 it is possible to a considerable extent to follow the general tendency of the river during these 28 years. In 1874 at Gondokoro the river was already leaving the right bank, and shortly after the station was removed to Lado (1875) since the water channel had become too shallow for boats to use it. Emin Pasha had his post there also, but now there is a sufficiently deep channel again alongside the east bank at Gondokoro. Below Lado the main channel, which now bends at once across to the right bank and hugs it closely for about 25 kilometres, seems at that time to have kept much nearer the left bank for about 18 kilometres

[1] Intell. Dept. W. O. 1878.

[2] Published in Blue book. Egypt No. 2, 1901, where however the sheets have been reproduced on different scales.

[3] Published in Report on the Upper Nile, plan VII.

before crossing; it then returns to the left bank and now keeps close to it for about 20 kilometres, which it also did in 1874. Ten kilometres north of the present Belgian station of Kiro, the river turns across its valley, but in 1874 it made a bend of about 90° while to-day it is not more than 45°. It now continues across the grass swamp which fills the valley until it arrives near its eastern margin which it follows closely until Bor (lat. 6° 36′ N.). In 1874 the river, shortly after leaving the left bank, turned again to the north at 5° 30′ N. lat. keeping approximately down the centre of the valley some 4 or 5 kilometres to the west of its present channel, the tract of land between the old and new channel being apparently the Chir Island, at the north end of which von Harnier spent the rainy season of 1861.[1] This channel still exists but is only navigable for steamers at flood stage, or in years when the water level is high.

In the next reach of the river from Bor to Kenisa, while maintaining its general direction and the larger curves, it has altered very much in the small bends especially in the southern part. This part is rapidly remodelling its curves, and many small changes have taken place between March 1901 and March 1903. For about 60 kilometres south of Kenisa the changes are much less.

Between Kenisa and Ghaba Shambe the river has kept its general position in its valley but the bends have changed considerably. Between Ghaba Shambe and Hellet Nuer the southern part has altered but little until the south end of the reach. From Ghaba Shambe for about 140 kilometres each bend to-day may be recognised on the map of 1874, altered perhaps in shape somewhat, and some have shifted their general position, but on the whole there is a striking correspondence between the two. The vast expanse of marsh east of this causes instability at this part by the rise of water-level in wet years. In the neighbourhood of Hellet Nuer where the old channel has only just been reopened, the river seems from the survey of 1874 to have flowed near the eastern margin of the lagoons through which the steamers passed while the proper channel was blocked, except at the northern end where the river made very sharp bend (Ghursa el Kilab) which no doubt caused the sadd block in recent years as it used to do formerly.

In this reach were two of the sadd blocks in 1878-1880. No. I block described by Emin Pasha (see p. 138) occupied the same part of the river as blocks 16-19 of 1900, while block II of the same year formed in the sharp angle of Ghursa el Kilab which doubtless caused the block-

[1] Pet. Mitt. Ergänzungsheft II, 1863.

ing of this part of the river where the true channel has only recently been re-opened.

The remaining reach of the Bahr el Jebel from Hellet Nuer to Lake No shows practically no change, and every bend can be traced on the survey of 1874. It was in this portion that most of the sadd blocks were found in 1900, 14 of them occurring between Lake No and Hellet Nuer.

It has been suggested[1] that the channel diminished greatly in width by 1874, but Watson's log-book gives no support to the statement that from 1874 to 1878 the Bahr el Jebel was clear of sadd but had dwindled to a clear waterway of 6 metres free from weeds over long reaches.

From Lake No to Hellet Nuer at the end of October 1874 he notes 2 spots where blocks of sadd existed (see Plate XI) not however closing the channel completely, and 2 cases of floating grass islands. The narrowest part was at the mouth which was only 25–30 yards wide, while between this point and Hellet Nuer the width of the water channel is given as 100–120 yards, 70 yards, 40 yards, but never less than this last dimension; Marno found the same in 1879.

Tabulating these observations we have:—

Gondokoro–Bor	:	Considerable shift of bed.
Bor–Kenisa	:	Smaller bends changed much.
Kenisa–Ghaba Shambe	:	Slower change in bends,
Ghaba Shambe–Hellet Nuer ...	:	Little change except where channel has been blocked and opposite the Zaraf Marshes.
Hellet Nuer–LakeNo	:	Very little change.

The effect therefore of the annual flood caused by the rains in the Latuka hills is unfelt beyond Bor and to the north of Ghaba Shambe the August maximum is due to local rains and not to the flood coming down the river; from Hellet Nuer onwards the river discharges an almost constant volume which varies but little at the different seasons of the year, or in different years. The marshes which occupy the flood plains of the valley absorb all the surplus supply, while those in the valleys of the Gel, the Yei, and other minor tributaries do the same to the flood waters of these streams.

The water level of the Bahr el Jebel at Gondokoro is at its lowest about April in which month the first rains begin, but usually there has been very little change for one or even two months previously. The other gauges are Mongalla since April 1903, Bor for which readings

[1] The Nile in 1904, p. 40.

begin in March 1905, and Ghaba Shambe where a gauge was established in September 1903. The maximum level is usually reached in September at Gondokoro, but in 1904 it was highest in August since in that year the autumn rains failed throughout the Sudan and Abyssinia and apparently in the north districts of Uganda also. At Ghaba Shambe the maximum in both 1903 and 1904 was at the end of September and the minimum in 1904 in March, the rise and fall being very steady. The are a few earlier observations which may be recorded here.

Dovyak[1] of the Austrian Mission Station in 1853 took both river gauge and meteorological observations regularly from January 1853 to January 1854:—

River Level at Gondokoro ; January 1853 to January 1854.[2]

1853.		metres.	1853.		metres.
January	1	−0.05	September	1	+1.50
February	1	−0.05	"	9	+2.00
March	1	0.00	October	1	+1.20
April	1	0.00	"	10	+1.50
May	1	0.00	November	1	+0.90
June	1	+0.60	December	1	+0.90
July	1	+0.90	1854.		
August	1	+0.90	January	1	+0.88
"	21	+1.40	"	28	+0.86
Range in 1853=2·05 metres.					

In 1861 Peney[3] records at Gondokoro that the first marked rise of the river took place on 16th April. It then rose 1·25 metres and after 24 hours began to fall. On May 17 it rose to 1·15 metres above the lowest level and on May 23 to 1·23 metres. In June it varied between 0·33 metre above the lowest level on the 13th and 1·10 metres on the first, the mean of the month being 0·52 metre.

The rainy days for these months were:—

	days	millimetres
April	10	—
May	9	105
June	14	277

For 1857 and 1858 there are some observations by Kaufmann of the of the same Mission,[4] who states that between August 1857 and August 1858 the greatest difference between highest and lowest water at Gondokoro was 5 ft. 4 in or 1·63 metres.

[1] Pet. Mitt. 1859, p. 306. The values differ slightly from those given by Lombardini.
[2] From "Essai sur l'Hydrologie du Nil," Lombardini, Milan, 1865, Plate III.
[3] Bull. Soc. Geog. July 1863.
[4] Pet. Mitt. 1861, p. 368, and "Das Gebiet des weissen Flusses," Kaufmann, Brixen 1861.

At Kenisa (Heiligenkreuz) in 1859 the difference is said to have amounted to a little over a klafter (=1.896 metres) but this must have been due to the exceptionally heavy rains.

In 1861 at a zeriba on the west bank of the river at the northern end of Chir Island in latitude 6° N. von Harnier[1] notes on 17th April a sudden rise of the river of several feet, the water being of a reddish colour, which flooded all the low lying land; on the next day the river fell equally. On May 11 the river began to rise markedly, being reddish in colour and carrying reeds and drift wood.

At Kenisa on the 22nd September 1861 the river was still rising and did not begin to fall till 10th October.

In this year when von Harnier was at Kenisa it is stated that the whole country was flooded, the missionary station being left as a small island in the water.

In 1872 Sir S. Baker[2] recorded the water level at Gondokoro from December 1871 till November 1872; the lowest water occurred in the first days of April, and the highest at the beginning of September. The mean water levels were:—

1871.	metres	1872.	metres
December	0·93	June	0·81
1872.		July	1·05
January	0·89	August...	1·31
February	—	September	1·47
March	—	October	1·24
April	0·15	November	1·09
May	0·46		

Greatest range=1·32 m.[3]

In 1874 Lieut. Watson R.E.[4] noted that the level of the river at Gondokoro on 19th November was 2 ft. 6 in. (=0·75 metre) below the maximum of that year.

In the years 1876, 1877, 1878, regular observations were taken at Gondokoro, and the curves are given by Chélu:—[5]

YEAR[6]	LOWEST STAGE	GAUGE	HIGHEST STAGE	GAUGE	RANGE
		m.		m.	m.
1876	About April, 1 ..	−0·02	September, 1.. ..	+2·02	2·02
1877	„ „ 6 ..	−0·11	August, 16.. ..	1·45	1·56
1878	„ „ 1 ..	+0·21	„ 22.. ..	2·30	2·09

1 Pet. Mitt. Ergänzungsheft II., pp. 138-140.
2 Pet. Mitt. 1875, p. 343.
3 Ismailia I.. p. 316 gives the rise up to 30 July 1871 as 4 ft. 6 in.=1·37 metres.
4 M. S. Notes of his survey of the White Nile and Bahr el Jebel kindly lent by him.
5 "Le Nil, Le Soudan, L'Egypte," Paris, 1891, p. 13. (Communicated to him by Emin Pasha.)
6 Data taken from Chélu's diagram.

In the year 1878 the river was exceptionally high and the station at Lado was flooded; the rains were late and heavy.

In 1884 Junker notes at Lado that on April 26 the river had at last risen a little.

The results of the readings of the gauges erected in 1901 and subsequently are as follows:—

YEAR	LOWEST STAGE	GAUGE	HIGHEST STAGE	GAUGE	RANGE
		m.		m.	m.
1901	February 27-28 ..	−0·06	August 26	1·25	1·31
1902	June 23	−0·13	„ 24	1·75	1·88
1903	April 4-10	0·48	September 23, 24 ..	2·96	2·48
1904	February 26.. ..	1·48	August 24	3·10	1·62

Collecting these various data we can form a fairly accurate estimate of the average range of the river at Gondokoro.

RANGE OF BAHR EL JEBEL.

1853..	2·05 or 2·18	Gondokoro.	1877..	1·56	Gondokoro
1858..	1·63	„	1878..	2·09	„
1859..	1·90	Kenisa	1901..	1·31	„
1861..	1·25	Gondokoro.	1902..	1·88	„
1872..	1·37	„	1903..	2·48	„
1876..	2·02	„	1904..	1·62	„

mean 1·76 metres at Gondokoro.

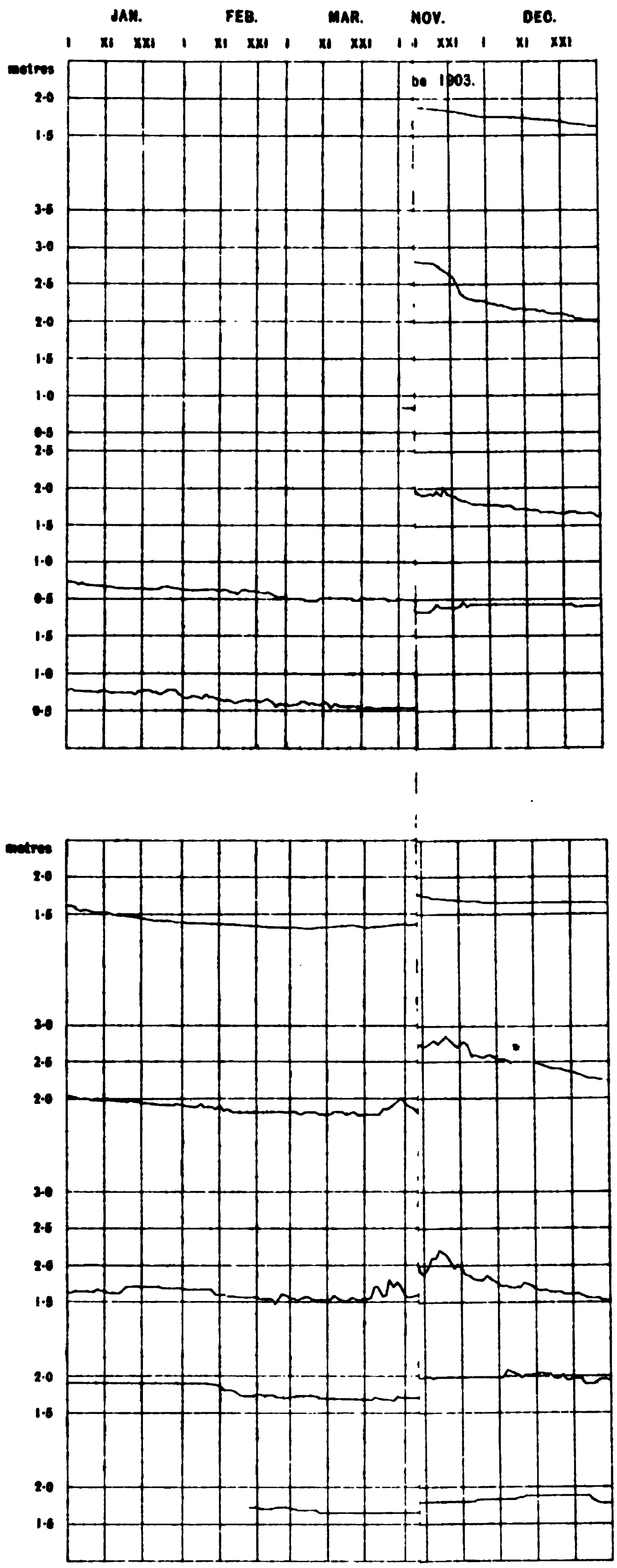
At Gondokoro gauge readings exist since 1900, but the gauges have been lost or moved on several occasions, and corrections have to be applied to make the readings of different years comparable. A sloping teak gauge was fixed on April 9, 1903 and since then this has been regularly in use. As there is no little confusion in consequence of the various changes, the following history of this gauge is given.

Observations were commenced here on 6th December 1900 after those which had been taken further up-stream, at Fort Berkeley from 1st September 1899 to 2nd December 1900 were discontinued. The gauge was a light wooden rod graduated in feet and inches. This may be called gauge A.

On March 27, 1901 a more substantial gauge of sheet iron screwed to a wooden upright, which was strutted from the bank, was fixed at the time of Sir W. Garstin's visit.[1] This may be called B and was divided into metres and centimetres.

[1] See Blue Book Egypt No. 2, 1901.

PLATE X.



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On the 13th November 1902 this was knocked down in the night and lost, and another, C, was erected on 18th November 1902 which was graduated in feet and inches.

To avoid the uncertainty caused by such frequent changes of gauge, on April 9, 1903, a sloping baulk of teak was fixed parallel to the slope of the bank and firmly anchored back into it, so as to be out of the way of boats and hippopotami. This baulk is graduated metrically and has a mark at each 5 centimetres. It is fixed at a slope of 60° so that its readings require to be multiplied by 0·866 to reduce them to vertical metres.

These changes may be tabulated as follows:—

Gauge	In use		Reading
	From	To	
A	6 December 1900	27 March 1901	Feet and inches.
B	28 March 1901	12 November 1902	Metric.
C	18 November 1902	8 April 1903	Feet and inches.
D	8 April 1903	to date	Metric.

Thus there has been a constant record, except from 13th to 18th November 1902. The correction of these different series of gauge readings with one another is therefore important.

On April 9, D gauge was erected and read 0·48 metre or 1 ft. 7 in. while the C gauge which it replaced read 4 in., thus the readings of C gauge require an addition of 0·38 metre to reduce them to those of D gauge.

A difficulty arises now in connecting B gauge with C in consequence of the interval of 5 days between the loss of B gauge and the erection of C gauge.

The recorded readings converted to metres are as follows:—

1902	metres
10 November	1·37
11 "	1·42
12 "	1·50
18 "	0·86
19 "	0·84
20 "	0·84

Thus to reduce the B gauge readings to the C gauge the correction will be 0·64 metre if there was no fall or rise of the river between 12th and the 18th of November.

The observer, has stated that he believes the river was stationary between these dates, but no note was made at the time. On the

March 28, 1901 B gauge was fixed and read 0·30 metre when A gauge was reading 1 ft 6½ in. thus the correction to correct its readings to those of B gauge is 0·16 metre.

These corrections are given in the following table:—

Gauge	CORRECTIONS TO REDUCE TO			
	A	B	C	D
A	$0^m\cdot00$	$-0^m\cdot16$	$-0^m\cdot80$	$-0^m\cdot42$
B	$+0^m\cdot16$	$0^m\cdot00$	$-0^m\cdot64$	$-0^m\cdot26$
C	$+0^m\cdot80$	$+0^m\cdot64$	$0^m\cdot00$	$+0^m\cdot38$
D	$+0^m\cdot42$	$+0^m\cdot26$	$-0^m\cdot38$	$0^m\cdot00$

There is reason to believe, however, that the river must have fallen in the interval between gauges B and C. The amount of the fall necessary to render the discharges which were taken in 1901-2-3 consistent, is 0·287 metre. Since the river is falling in general in November, it is probable that its level was not maintained constant between gauges B and C. Moreover observations made by the flood discharge party in 1903 at Mongalla, Lado and Gondokoro show that the difference in level between the 1902 and 1903 floods was about 0·90 metre, whereas the difference on the gauges is 1·24 metres; thus additional correction of about + 0·30 metre to gauge-readings on B and consequently A is thereby indicated.

A sudden drop is shown by the Gondokoro gauge readings on the 1st-4th December 1903 [1] which has since been found to have been due to an error of reading and all readings subsequent to this date require a correction of + 86 centimetres. On December 1, 1903 the reading of the vertical height of the river was 1·77 metres and on the 4th it is given as 0·89, or 88 centimetres lower though before and after these dates the river was practically stationary. Moreover no such fall was shown by either the Wadelai or Mongalla gauges.

On Plate X the curves plotted from the gauge readings at Gondokoro, Mongalla, and Ghaba Shambe show well the general character of the river's flood; the sudden flushes due to rainstorms in the eastern hills raise the water level rapidly at Gondokoro and Mongalla, but long before Ghaba Shambe is reached their effect is lost in the numberless channels which intersect the flood plain, and in the middle reaches a steady rise due to the local rainfall is the result. Peney from his own discharge observations south of Gondokoro at the Makedo rapids deduced a discharge at low stage of 330 cubic metres per second,

[1] Report on the Upper Nile. Plan IV.

a result which Lombardini[1] revised, and considered 562 cubic metres per second to be a more probable value, a result remarkably borne out by recent investigations.

To study the hydrography of this part of the river it is convenient to consider it in three sections which, though not sharply distinct from one another where they join, do on the whole present characteristics more marked in one reach than in the others. From Gondokoro to Bor there is a large volume of water, straighter reaches with less tendency to meander, well defined banks from 1 metre to 1·5 metres above low-stage water level, deposits of coarse sand and even gravel in the southern parts, while at each change of direction a bank of coarse sand is deposited in the slack water on the concave side of the stream-bend. From Bor to Hellet Nuer the river meanders excessively as it winds across its flood plain; sandbanks are infrequent as the flood waters have dropped the greater part of their load before this, but small bends are rapidly modified, every year witnessing slight changes, though the general shape of the larger bends are maintained; banks are from 0·5 to 0·8 metre above low stage level. The flood rise is gradual and slow as the Ghaba Shambe gauge shows.

From Hellet Nuer to Lake No the water carries no appreciable load and the rise in flood is very slight though the action of the Sobat flood water (see p. 141) raises the level slightly for some distance from Lake No. Generally speaking the river here carries an almost constant volume throughout the year, and has therefore eroded a suitable section which it has no tendency to change, and the comparison which has been made above shows that the bends have changed but little in the last 30 years. The banks are low but there is no erosion to speak of since the volume and velocity are almost constant and as it carries no load, even in the rainy season, there is no building up of banks by deposit from its flood waters.

Reliable data of the volume passing down the river are furnished by the series of measurements taken during the past four years[2] both at low stage and during the flood season, and sections of the river where they were made are given on Plate VIII. The black portion shows the section drawn to true scale.

In the Gondokoro—Bor reach these have been taken just upstream of Lado, at Mongalla, and above Bor close to the site of the camp of the dervish Emir Arabi Abdalla, thus furnishing a series over a length about 160 kilometres of river. At Lado alone is it certain (when the

[1] "Essai sur l'hydrologie du Nil," Milan, 1865, p. 39.
[2] A report on the Upper Nile, 1904, p. 149.

volume of a small channel has been added) that the whole river has been measured, west of both the Mongalla and Bor main channels there are others carrying a certain volume northwards which are not included.

PLACE	Kilometres from Albert lake	DATE	Width	Mean depth	Section-al area	Mean velocity	Dis-charge	Gondo-koro Gauge reading
			m	m	m²	m.p.s.	m³.p.s.	m
Lado.. ..	404	28-3-1901	231	3·37	779	0·726	566	0·22
„	„	1-4-1903	228	2·58	615	1·069	641	0·19*
„	412	14-5-1904	293	3·33	1084	1·109	1138	1·39*
„	404	9-9-1902	223	4·62	1033	0·929	960	0·85
„	„	9-9-1903	228	5·60	1347	1·372	1847	2·03*

* 30 centimetres have been deducted from the gauge readings recorded on each of these dates since all available evidence seems to shows that when no gauge existed from 11-18 November 1902 the river fell by this amount.

To four of these discharge the volume of a small channel east of the main stream has to be added.

PLACE	Kilometres from Albert lake	DATE	Width	Mean depth	Sectional area	Mean velocity	Discharge
			m.	m.	m².	m.p.s.	m³.p.s.
Lado ..	410	29-3-1901	70	1·10	77	0·741	57
„ ..	„	1-4-1903	70	0·54	38	0·616	52
„ ..	„	13-9-1902	80	1·54	123	0·968	119
„ ..	„	8-9-1903	71	3·24	228	0·983	224

So that the total discharges were:

	Low stage m³ p.s.		Flood stage m³ p.s.
29.3.01	623	9.9.02	1079
1.4.03	693	9.9.03	2071
14.5.04	1138		

that of 1904 being measured at a different point to the others. Comparing the volumes discharged, 1903 a year of heavy rainfall, shows the highest value but that of August 1904 must have been larger as the gauge readings were higher on account of the much higher level of lake Albert in this year and consequently the increased discharge from the lake as the Wadelai gauge records.

Scouring of the bed in 1903 to the extent of one metre at the point where the measurements were made near Lado has been assumed[1] though it is not clear on what ground, for while the mean depth increased from 4·62 to 5·60 metres the gauge reading increased from 0·85 to 2·03 metres, an even greater amount, and the flooding of the island opposite the Belgian station of Lado fully bears out the exceptional

[1] Willcocks. "The Nile in 1904," London, 1904, p. 23.

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height of the river. It is probable that deposition of sand and gravel would be greatest at the end of September and in October when the river commences to fall and waters coming from the reaches upstream where the grade is high would lose much of their load in the first reach of low grade especially on a falling stage. In April 1903 the Lado-Gondokoro reach was much more difficult for navigation than in 1901 although the water level as recorded on the gauge at Gondokoro was higher.

On the basis of the discharges which have been measured near Gondokoro a provisional discharge table [1] was worked out but it cannot be regarded as reliable. It is based upon three discharges measured at low stage about the beginning of April in 1901, 1903 and 1904 and on two others measured at flood stage—1902 and 1903, but these data are too few to control the values corresponding to intermediate readings of the gauge between the lowest and highest. The rapid rises and falls due to sudden floods coming down the larger tributaries complicate the question since a larger volume passes on a rising stage rather than on a falling one for a given gauge reading.

At Mongalla 32 kilometres below Lado the main channel was carrying 2046 cubic metres per second September 14, 1903 so that up to this point there was no great diminution of volume, but by the time Bor is reached it has greatly decreased and the rise and fall of the river level is slow and regular, no rapid variations being shown :—

PLACE	Kilometres from Albert lake	DATE	Width	Mean depth	Sectional area	Mean velocity	Discharge	Stage of river
			m.	m.	m²	m.p.s.	m³.p.s.	
Mongalla .	437	14-9-1903	239	6·11	1487	1·433	2046	Flood
Bor	561	11-5-1904	145	4·11	662	1·095	737	Low
„	„	16-9-1903	150	5·11	770	1·135	888	Flood

In the middle reach three discharges have been published up to the present time.

..	883	8-4-1900	65	5·10	332	0·559	180	Low
..	820	4-9-1902	115	4·31	498	0·799	398	Flood
..	„	18-9-1903	185	4·71	669	0·796	532	„

Here a large reduction of volume has taken place and the water-level rises slowly to a maximum in September (see Plate X); the actual volume in the main stream will vary from year to year according to the amount which the side channels may be carrying.

[1] Mr. J.I. Craig—Appendix IV of Report on the Upper Nile. Cairo, 1904.

In the third reach from Hellet Nuer to Lake No the volume of water shows but little variation.

PLACE	Kilometres from Albert lake	DATE	Width	Mean depth	Sectional area	Mean velocity	Discharge	Stage of river
			m.	m.	m²	m.p.s.	m³.p.s.	
Hellet Nuer	947	13-4-1903	94	4·08	392	0·883	331	Low
	943	1-9-1903	93	5·11	478	0·784	375	Flood
...	1003	1-4-1901	102	4·74	485	0·540	262	Low
...	1003	2-9-1902	101	4·72	511	0·652	333	Flood
Near mouth	1142	14-4-1900	52	5·08	262	0·836	219	Low
	1146	14-4-1903	76	5·58	424	0·706	285	”
...	1147	22-5-1904	74	6·20	459	0·701	324	”
...	1147	31-8-1903	79	5·62	441	0·722	318	Flood

In April 1859 de Malzac[1] measured the Bahr el Jebel above its junction with the Bahr el Ghazal and found it 187 metres wide and 5·75 metres for the mean depth, 10 soundings at 10 to 16 metres interval were taken; this together with the velocity recorded, 1·66 metres per second would give a discharge of 1226 cubic metres per second which is incredible, but if the velocity be halved the discharge is still abnormal. Petherick on April 25, 1863 made the volume discharged to be 235 cubic metres per second.

At Hellet Nuer in September 1902 Mr. J. I. Craig collected a sample of water which was subsequently analysed in the laboratory of the Survey Department.[2]

		Constituents per million parts.
Suspended matter	Organic matter	2·2
	Mineral matter	36·0
	Total suspended matter	38·2
Dissolved matter	Actual or saline ammonia	0·215
	Ammonia from organic matter	0·660
	Silica	28·70
	Iron and aluminium oxides	4·10
	Lime	15·70
	Magnesia	11·20
	Sulphuric Acid	Trace
	Nitric acid	Trace
	Nitrous acid	Nil
	Chlorine	10·44
	Potash and soda[3]	not detd
	Carbon dioxide and organic matter[4]	” ”
	Total dissolved matter[5]	164·00

[1] Bull. Geog. Soc., Paris, 1862, p. 219.
[2] By Mr. A. Lucas.
[3] Sample too small for determination.
[4] » » » » » but both were present.
[5] As actually determined.

Bahr el Zaraf.—The Bahr el Zaraf has always been treated as if it were a true branch taking off a share of the Bahr el Jebel but it is permissible to doubt whether this is strictly the case.

It seems very doubtful if "sadd" blocks in the Bahr el Jebel have ever diverted its water in any quantity to the Bahr-el-Zaraf. Records of such obstructions are few but it is known[1] that only in 1879 was the main channel blocked near Ghaba Shambe, and in 1879 and again of late years at Ghursa el Kilab, a point just up stream of Hellet Nuer; but neither Emin Pasha in 1879 or the Sudan Government steamers in recent years found any serious difficulty in passing these obstacles by side channels or the lagoons formed by the flooded areas of swamp. In either case there seems no reason to suppose that much water was diverted to the other stream, and certainly neither Baker in 1870 and Henri in 1900 found their passage through the intervening swamps much facilitated, when the Bahr el Jebel was blocked.

In the net-work of channels which intersect the swamps east of Ghaba Shambe there have always been some which have carried water into the low ill-defined swamp area which supplies the upper part of the Bahr el Zaraf with its water;[2] at times some one channel may possibly have been scoured out when the Bahr el Jebel has been blocked by sadd near this point, sufficiently to connect the Bahr el Jebel and the Bahr el Zaraf by a navigable waterway but no record exists of such a state of things except when Sir S. Baker, on his return in June 1873, found that the channel which he had cut in 1871 was still open. When Commandant Henry in 1900 passed up the Bahr el Zaraf and into the Bahr el Jebel, he had the greatest difficulty in doing so, having to traverse channels but a metre or two wide, and at other points open sheets of water only 20 centimetres deep,[3] though the Bahr el Jebel was blocked at the time.

It has a meandering course of about 340 kilometres but for the last 30 kilometres it can no longer be recognized as a river amid the lagoons and minor water-channels which intersect the low-lying plains. Its banks do not rise above the general level of the plain as they would had it been a silt-carrying river, and indeed there is no part of its course where there is any considerable erosion going on for it to obtain a load except what a rainstorm may wash in; starting from shallow swamps it flows down the slope of the country and like many similar streams

[1] p. 138.
[2] Liddell. Geog. Jour. Dec. 1904 p. 651 and Report on the Upper Nile Appendix VI.
[3] Bull. Soc. Etudes Coloniales 1902. Nos. 1-11. Brussels 1902.

on the alluvial plains east of the Bahr el Jebel and south of the Sobat, it has cut down directly into the sandy alluvium sufficiently deeply to carry its ordinary volume. This eroding action is probably assisted in its early stage by the heavy storms of rain which fall very locally, flooding the lower lying depressions which are drained off into these surface streams like the Bahr el Zaraf, the Khor Filus, and the upper Pibor; if the area which can be so drained is large the stream soon scours a well defined channel for itself. But such rain-water draining from open flooded plains can carry no large load of silt, so that it is erroneous to say that the Bahr el Zaraf once carried water other thanthat brought down by Bahr el Jebel since it has banks of solid earth.[1]

These banks were not formed by the present stream but are part of the great alluvial flood plains formed from the destruction of the old plateau to the south, of which Jebel Zaraf is no doubt an outlier; and they were laid down before the present stream commenced to flow.

At the time (1840) of the expeditions sent by Mohammed Ali to discover the sources of the Nile, no mention is made of this tributary, but its mouth may have been screened by vegetation, nor is it mentioned by Knoblecher in 1849. In December 1853 Petherick[2] described this river at its mouth as about half the size of the Sobat, that is about 45 metres wide. Between that time and 1861 it was well known to the ivory hunters and slave traders whose men traversed its whole length and found no difficulty in taking boats up it.[3]

The earliest measurement of it that we have is by de Malzac[4] on the the 5th April 1858 :—

Distance from left bank in metres	1·5	4·5	10·5	13·5	15
Depth, in metres	1·4	1·7	2·3	1·5	0

giving a sectional area of 24·4 sq. metres while the velocity was 21·35 metres per minute or 0·356 metre per second ; which corresponds to a discharge of 8·7 cubic metres per second. It was therefore at this time little more than a drain for the rainy season.

In 1863 Petherick measured a discharge also in April, and obtained a result of 1655 cubic feet or 47 cubic metres per second. Both of

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1 Willcocks. "The Nile in 1904," p. 36.
2 Egypt, Sudan and Central Africa, p. 361.
3 Bull. Soc. Geog. V. 3 p. 49 Paris 1862.
4 Bull. Soc. Geog. IV.2, June Paris 1862.

these discharges were apparently measured near the junction with the White Nile.

On 4th January 1863 Baker[1] describes it as a small river, while Heuglin[2] on 3rd February 1863 remarks that little is to be seen of the Bahr el Zaraf when passing its mouth. It is not therefore admissible to say that the Bahr el Zaraf did not exist in 1840 because Werne did not notice its mouth in passing, still less to assume that it was formed by the spills and branch channels of the Bahr el Jebel being widened and deepened by the negroes as a measure of protection against the slave traders,[3] on the strength of a rumour recorded by Werne [4] that the river had been blocked below the expedition. It had probably dwindled temporarily to an unimportant stream as rain had been feeble for several years; its junction with the White Nile was probably hidden by reeds and grasses.

A few years later the sadds in the White Nile between the mouth of the Bahr el Zaraf and Lake No and in the Bahr el Jebel had become so formidable that the traders were compelled to pass up the Bahr el Zaraf to reach the the upper reaches of the Bahr el Jebel. In 1870 Sir Samuel Baker had to follow this route, but by this time the channel had become larger. On 17th February 1870 he found it[5] at its junction with the White Nile.

180 feet or 54 metres in width,

19 feet or 5·7 metres deep and flowing with a velocity of 3½ miles per hour or 1·56 metres per second. From this has been deduced a sectional area of about 230 square metres, and an approximate discharge of about 360 cubic metres per second. At this time the water level was 5 feet or 1·5 metres below the marks of high water.

But this discharge of 1870 would be an abnormally large one compared with the others which have been taken and the explanation appears to be that the depth given is the maximum and not the mean depth. On March 16, 1903 the maximum depth was 5·2 metres, and the mean depth 3·6 metres so probably 3·5 metres may be taken as ample for the mean depth in this case. The velocity is given as 3½ miles an hour which has the look of an estimated velocity rather than a measured one and may easily be too high; indeed if compared with even the low stage velocities of the lower part of the Bahr

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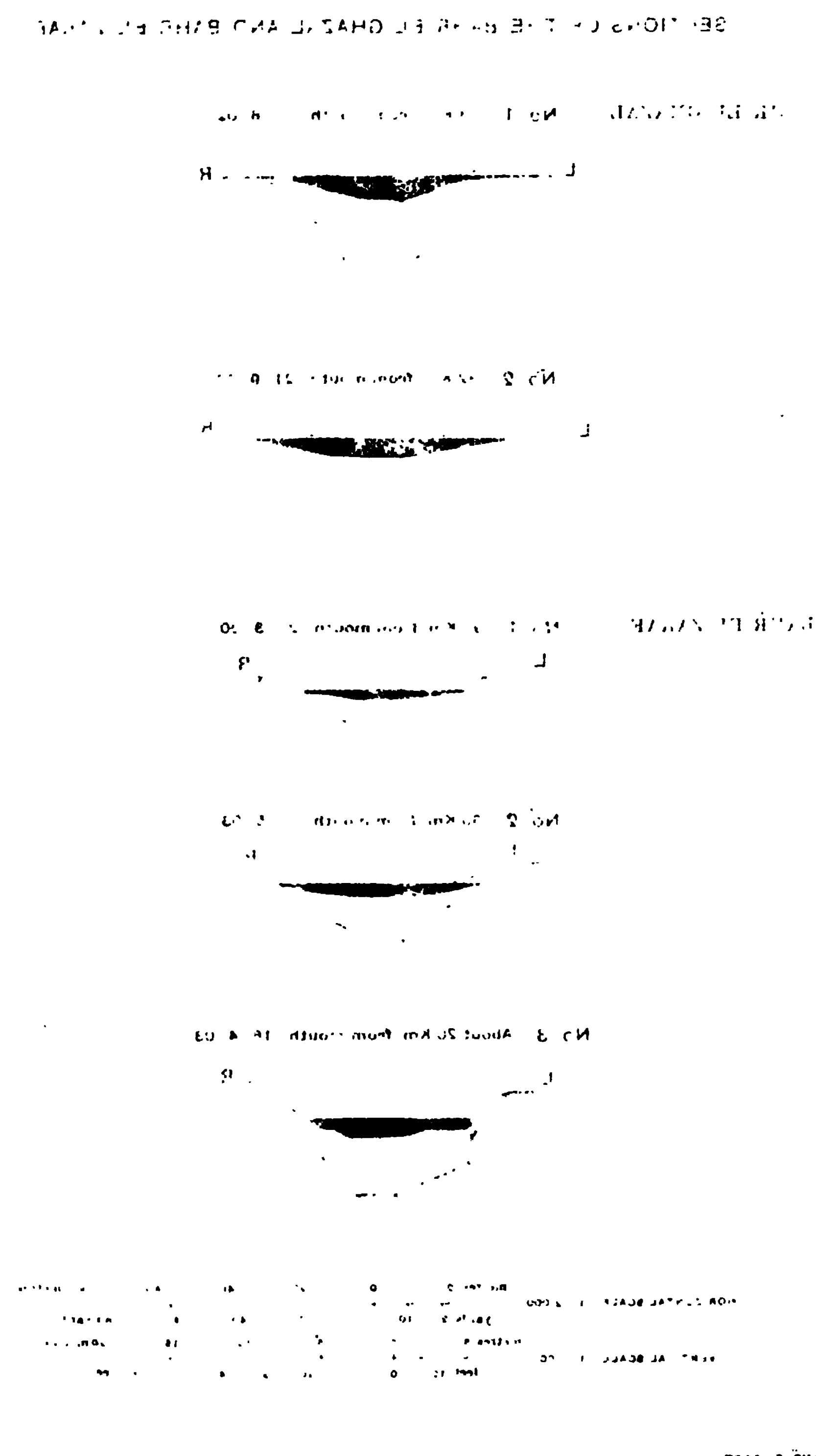
1 Albert Nyanza, p. 31.
2 "Reise in das Gebiet des Weissen Nil," Leipzig 1869, p. 99.
3 "The Aswan Dam and after," p. 16.
4 The White Nile, London 1849.
5 Pet. Mitt. 1871, p. 23.


SECTIONS OF THE BAHR EL GHAZAL AND BAHR EL ZARAF
BAHR EL GHAZAL
No 1
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L
No 2
BAHR EL ZARAF
No 1
No 2
No 3 About 20 Km from mouth
HORIZONTAL SCALE
VERTICAL SCALE
SURVEY DEPT

In September 1902 a sample of water was collected by Mr. J. I. Craig 15 kilometres from the mouth and analysed in the laboratory of the Survey Department.[1]

		Constituents per million parts.
Suspended matter	Organic matter	2·4
	Mineral matter	61·8
	Total suspended matter	64·2
Dissolved matter	Actual or saline ammonia	0·100
	Ammonia from organic matter	0·340
	Silica	38·30
	Iron and aluminium oxides	4·60
	Lime	25·30
	Magnesia	17·40
	Sulphuric acid	Trace
	Nitric acid	„
	Nitrous acid	Nil
	Chlorine	6·96
	Potash and soda[2]	not detd
	Carbon dioxide and organic matter[3]	„ „
	Total dissolved matter[4]	220·00

A number of discharges have been measured in recent years but all show the Bahr el Zaraf to be an unimportant stream and bear out the conclusion arrived at above that in Baker's time the volume discharged was in all probability between 100 and 150 cubic metres per second.

VOLUME DISCHARGED BY THE BAHR EL ZARAF.

DATE	Width	Mean depth	Max. depth	Sectional area	Mean velocity	Discharge	Kilom. from mouth	AUTHORITY
	m.	m.		m².	m.p.s.	m³.p.s.		
April 4, 1858	15	1·75	..	26	0·356	9	‡	De Malzac[5]
April, 1863	..	..	..	..	..	47	‡	Petherick
Feb. 17, 1870	54	3·5*	5·7	189*	0·600*	113*	‡	Baker
Mar. 25, 1900	47	1·94	2·7	91	0·353	32	96	Garstin
April 3, 1901	47	2·94	4·2	138	0·239	33	19	„
April 16, 1903	50	3·60	5·2	179	0·304	50	20	„
May 8, 1903	53	1·90	5·8	110	0·550†	61	128	Wilson
Aug. 30, 1902	50	4·52	6·8	222	0·364	81	20	Craig
Sept. 22, 1902	67	3·58	7·2	240	0·404	97	8	„
Aug. 29, 1903	56	3·22	7·2	180	0·611	110	14	„
Sept. 22, 1903	59	3·93	7·5	232	0·658	158	20	„
May 23, 1904	43	4·02	6·5	228	0·606	133	18	Garstin

* See p. 119. † Surface velocity. ‡19 Near mouth.

[1] By Mr. A. Lucas.
[2] Sample too small for determination.
[3] „ „ „ „ „ but both were present.
[4] As actually determined.
[5] Bull. Geog. Soc., Paris, 1862, June.

It is certainly incorrect to consider the Bahr el Zaraf as a branch of the main stream analogous to the bifurcations which take place in the deltas of silt-carrying streams where the main stream builds up banks parallel to its course by the deposition of its silt, until finally the flood plains further from the main channel lie at a lower level than the flood level of the river. If these banks are breached an arm of the river is formed which flows through these lower lands to the sea, becomes permanently an arm of the main stream, and gradually builds up its own banks in a similar manner. The Bahr el Zaraf shows no sign of having been so formed, but rather that it has cut its bed out of the alluvial plains so as to drain off the annual rainfall of that part, which it seems to effect by discharging a volume which varies from 30 cubic metres per second in dry years up to about 170 in rainy ones. But the measurements taken in May 1904 show that if the water level at low stage is high in consequence of the Albert lake being high, the marshes in which the Bahr el Zaraf rises are more submerged and a larger volume is drained off, while heavy summer rainfall on the marshes east of Ghaba Shambe will also give a good supply at low stage, 1905-6.

The Bahr el Ghazal.—The Bahr el Ghazal basin includes an area of about 552,100 square kilometres, made up of the province of the same name, the south-western corner of Kordofan, and the greater part of Darfur, but on account of the peculiar physical conditions in the area where the run-off finally collects, the rainfall of this great basin is almost without effect upon the Nile. In consequence of this, less attention has been devoted to this part of the Nile Basin than to other parts, but it is far from being wanting in interest since it repeats in its streams from the south on a smaller scale the same rapid transition from a stream in its hill stage flowing down a narrow rocky bed with considerable velocity, to the level flood plain where it occupies a wide and shallow valley which in its lower portion becomes a swamp, flooded in the rainy season as we have seen in the Bahr el Jebel. The basin is bounded on the east by that of the Bahr el Jebel, while on the south side the limit follows the Nile-Congo watershed to a point somewhat west of Hofrat el Nahas; from this point it runs almost north for about 550 kilometres through Jebel Marra, and then turns south-east in a nearly straight line to lake No. Except Jebel Marra (about 2000 metres) the altitude of the basin is everywhere moderate, and only rarely does the line of the south and south-west watershed reach 1000 metres above the sea.

The character of the country changes from south to north from park

passing through savannah and finally into steppe conditions in Kordofan. All along the southern limits of the basin is a fertile country with numerous groups of trees, especially near the streams, the wood-land savannah of Schimper,[1] while further north the true savannah occurs, with trees growing in the valleys of the rivers, the "gallery forests" of Schweinfurth.[2] In the lowest reaches of the rivers, where owing to the feeble slope of the country the ground is always water-logged, swamp vegetation replaces the shrubs and trees of the porous laterite soil of the middle reaches. To the west savannah alone occurs, while north of the Bahr el Ghazal and Bahr el Arab in consequence of the rapidly diminishing rainfall and the increased effect of the dry north-east winds which blow for 8 months of the year, the savannah type of vegetation becomes more and more typical of a dry climate, scattered patches of thorn forest occur till at last it gives place to true desert, but this lies outside the limits of the Bahr el Ghazal basin.

The geology of this part, so far as it is known, seems fairly simple. The gneiss, more or less granitoid in character, crops out as low round hills, or sometimes as steep crags, from the deposit of laterite which usually covers it, the decomposition product of the gneiss itself. The laterite in its more ferruginous portions furnishes the natives with an iron ore which they smelt and work. At Hofrat el Nahas copper occurs and is worked by the natives. Further to the north Jebel Marrah is a granite mass and forms part of a worn down range of crystalline rocks which extends through Kordofan. The lower portions of the basin are filled with a sandy mud washed down from the higher lands and mixed with the carbonaceous material derived from the decay of the swamp vegetation.

Climate.—The climate does not differ in the southern part from that of corresponding portions of the Bahr el Jebel, while the northern part corresponds rather with that of Kodok and the southern portion of the White Nile. At Wau alone have any observations been taken and these are given in the following table.

WAU

DATE	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
	Mean Temperature (Centigrade)												
August 1902–July 1903 and June 1904–April 1905	25·7	25·8	29·0	30·4	28·7	26·6	25·2	25·6	26·4	26·4	26 0	24·0	26·6

[1] Plant Geography, Ch. V.

[2] Heart of Africa, vol. 1, p. 504.

WAU (*continued.*)

DATE	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
	Mean Maximum Temperature												
June 1904–April 1905	35·1	36·1	38·0	38·6	..	31·7	29·8	30·3	32·3	33·2	34·2	33·9	33·8
	Mean Minimum Temperature												
" "	18·1	18·4	21·1	23·6	..	21·7	20·5	20·9	20·7	20·2	19·3	16·1	20·1
	Mean Daily Range												
"	17·0	17·7	16·9	14·4	..	10·0	8·8	9·4	11·6	13·0	14·9	17·8	13·8
	Mean Relative Humidity % (at 8 a.m.)												
"	45	26	37	44	..	78	82	83	79	78	61	37	59
	Total Rainfall												
1902 Rainy days ...	..	..	..	..	..	..	..	15	18	13	5	..	51
1903 Rainy days ...	0	1	3	10	19	9	21	26	..	..	..	..	89
1904 in mm.	<	36	>	19	134	169	107	120	77	46	10	0	718
1905 in mm.	0	0	0	25	84	174	94	266	146	60	99	0	948
Mean...	..	..	..	22	109	172	100	193	112	53	54	0	833

PERCENTAGE FREQUENCY OF WINDS

Wau.—August 1902—July 1903 and June 1904—April 1905 (8 a. m.)

MONTH	N.	NE.	E.	SE.	S.	SW.	W.	NW.	CALM
January ..	92	0	0	0	3	0	0	0	5
February ..	98	0	0	2	0	0	0	0	0
March.. ..	92	0	0	0	0	8	0	0	0
April	36	0	0	17	30	17	0	0	0
May	0	0	0	0	100	0	0	0	0
June	17	0	0	18	65	0	0	0	0
July	29	0	0	19	27	2	0	23	0
August ..	24	2	0	8	0	5	0	29	32
September ..	0	3	0	12	0	50	0	0	35
October ..	0	6	0	35	0	0	0	0	59
November ..	39	10	0	19	0	0	0	0	32
December ..	73	10	0	3	0	0	0	0	14

On the laterite plateau of the Bahr el Ghazal region a dry and a wet season are sharply demarcated;[1] the rains cease in November, the NE. winds commence, and the sky clears. This clear weather continues throughout the winter, until May, when clouds begin to gather and the wind shifts to the south and south-west, while the first showers of rain fall and thunder-storms are not infrequent.

[1] Dyé, Ann. de Geog. 1902, p. 324.

During the rains the temperature varies little, the mean being about 28°C while the minima usually lie between 21° and 24° and the maxima between 34° and 35°, while the humidity is high.

Schweinfurth[1] notes that in 1870 he experienced 10 days rain in July, 12 in August, and 10 in September, but the rainfall was extremely heavy, and crops in low-lying areas were much damaged.

The observations of Dr. Junker, and Emin Pasha, as well as some of Bohndorff and Casati have been discussed by Dr. A. Schmidt.[2] For the rainfall the number of rainy days are given. However most of the places where observations were taken lie just outside the Nile Basin. Ndoruma where Bohndorff was from July to December 1880 lies in long. 27° 25′ E., practically on the watershed between the Nile basin and that of the Congo; of the other places, Ssassa and Semio are but 150 kilometres S.W. of the water parting which is of no height at this part. Tangasi and Gadde lie considerably further to the south, nearly in the latitude of Wadelai.

All streams west of the Yei river flow from the Nile-Congo watershed into the Bahr el Ghazal or one of the rivers which go to form it. Taking them from east to west we have:—

Nam-Rohl	Jau	Tonj	Molmul
Jur or Suei	Wau	Bongo	Lol

From Hofrat el Nahas and Darfur comes the Bahr el Arab, while from the north comes a swampy khor some 70 kilometres long known as Ragabat el Seki, which is shown on most maps as the Keilak, whereas this is a tributary of the Bahr el Arab.

The Rohl, called the Aire in its upper reaches, rises in lat. 4° 30′ N. and flows in a northerly direction till it meets the Bahr el Ghazal about 30 kilometres west of the Bahr el Jebel. Junker followed the course of this river in 1877 and crossed it at several points.[3]

In lat. 4° 40′ N. it was 10 metres wide and 1·5 metres deep in May; 20 kilometres further north it was 20 metres wide when in flood, rising rapidly but soon subsiding again; in this part of its course there are water-falls and several rapids so that here it is a stream in its mountain tract. At Mvolo in lat. 6° N. Schweinfurth[4] crossed it December 17 1869 and describes it as flowing between banks 6 metres high, a stream 21 metres wide, 0·75 metre deep and with a velocity of

[1] Heart of Africa II, p. 281.
[2] Pet. Mitt. Erganzungshefte 92, 93.
[3] Junker "Travels in Africa," I. pp. 301, 376, 381, 384.
[4] Heart of Africa I. 377.

0·5 metre per second; it is probably here in its valley tract for at the end of July 1877 Junker found it 80 metres wide flowing as a placid stream between banks 2 to 3 metres high. About 56 kilometres lower down at Ayak (500 m.[1]) it enters its plain tract and flows in a bed some 40 metres wide in a valley flooded in the rains. Junker found it here at the end of July 1877 160 metres wide and 2 to 2·5 metres deep, while in the wet year of 1879 Felkin[2] found it 40 metres wide, 3·5 metres deep and flowing at 0·5 metre per second, thus discharging 70 cubic metres per second, but the flooded valley here seems to be treated as stagnant, and not contributing to the discharge.

The Jau rises in lat. 4° 40′ and flows northwards; where crossed by Schweinfurth in lat. 6° N. it was, in January 1870, 12 metres wide and 1 to 1·5 metres deep, but was 4 metres deep in flood. It seems to enter its plain tract about lat. 7° N. near Lang (470 metres) and was found in January 1877 by Junker[3] to be 180 metres wide and larger than the Rohl at Ayak. Felkin gives for about the same place in October 1879, 40 metres wide and 4·5 metres deep, flowing 0·75 metre per second. If the mean depth be considered 3 metres this would correspond to a discharge of about 90 cubic metres per second. When crossed by Felkin the country west of this point drained by the Khor Makaki was flooded to a depth of from 60 to 150 centimetres.

The river Tonj rises as the Ibbah in lat. 5° 15′ N. and flowing in a northerly direction finally joins the Jur to form the Bahr el Ghazal at Meshra Rek. Schweinfurth crossed it on June 24 1870 near Mbomo Zeriba[4] where the banks were high and well wooded; here the river was 18 metres wide, depth nowhere less than 3 metres, and the velocity about 0·58 metre per second, corresponding to a volume of 31 cubic metres per second. It enters its plain tract in about 7° 10′ N. lat. near Jur Ghattas, and was found by Schweinfurth[5] in April 1870 flowing between precipitous banks 4 metres high, 1 to 2 metres deep, and some 10 metres wide; in November it was 60 metres wide, and flowing 0·60 metre per second. In the wet season[6] July 1870, he found it 30 to 35 metres wide, 7 to 8 metres deep, and flowing 0·40 metre per second, equivalent to discharging a volume of 80 cubic metres per second. The valley for 3 kilometres on the left bank was a metre under water.

[1] Junker and Hassenstein "Pet. Mitt. Erganzungsheft," 93.
[2] Uganda and the Sudan II. p. 143.
[3] Travels in Africa, Vol. 1. p. 398.
[4] The Heart of Africa, II. p. 244.
[5] The Heart of Africa, I. p. 181.
[6] The Heart of Africa, II. p. 269.

The Molmul has a short course rising but a little to the south of Jur Ghattas and flowing to the Bahr el Ghazal a little west of Meshra Rek.

The Jur, formed by the junction of the Wau and the Suei, is the principal tributary of the Bahr el Ghazal; of the two the Suei is the principal stream rising in Mount Baginse which has an altitude of 1250 metres in lat. 4° 25′ N. and flowing northwards, at first in a ravine excavated in the plateau and filled with a dense growth of trees, while on the plateau itself the park or savannah type of vegetation prevails. By lat. 6° the altitude of the plateau has fallen to about 700 metres while on reaching Wau, where it enters its plain tract, the level is not more than 450 metres above sea level and is probably less. From lat. 7° 20′ N. its character begins to change and the river no longer flows in its bed cut in the plateau, but a broader valley opens out which is flooded in the rainy season, sand banks appear in the bed at each bend of the river, and rocks become fewer. By lat. 8° N. the valley widens considerably and soon after opens out into the marshy plains of the Bahr el Ghazal; rocks no longer appear and trees become rare, while flat alluvial deposits of sand and clay, on which grow reeds and grasses, replace them. The Jur is navigable for part of the year only, its waters falling too low in the spring and early summer to admit of the passage of steamers; up to the latter part of October however steamers of light draught can go about 110 kilometres above Wau at which point there is a small rapid; about 20 kilometres further south a ridge of rock prevents access to the upper reaches in boats. Von Heuglin crossed the Jur downstream of Wau on April 1, 1863 and found the water surface 160 metres wide, flowing between banks 4 to 5 metres high with a velocity of about 0·4 metre per second. Felkin crossed both tributaries a short distance above the junction in October 1879 and found the Jur 180 metres wide and very deep; the Wau was 72 metres wide.[1] Schweinfurth gives several measurements of the Jur all taken in about lat. 7° 30′ N. within a few kilometres of one another and the results are arranged from north to south in the following table :—

DATE	Width of water	Depth	Surface velocity	
	metre	metre	metre per second	
April 28, 1869 ...	24	0·3–1·2	...	...
May 8, 1869 ...	90	0·1–1·2	...	...
Oct. 27, 1870 ...	90	4·8–6·0	0·6	Valley flooded.
Dec. 18, 1870 ...	99	0·1	...	...
Dec. 25, 1870 ...	150	0·1	...	About half flood.

[1] Uganda and the Egyptian Sudan, II. 175.

The Wau is the smaller stream and in January 1871 was 43 metres wide and 1 metre deep flowing with a velocity of 0·5 metre per second.[1] Felkin near the same point found it in October 1879 72 metres wide and flowing 1 metre per second, it is here in a broad flat valley which is flooded in the rainy season for several hundred metres, but in the dry season it consists of a series of pools with small rills of water trickling over a sandy bottom.

At the present Wau post the rise and fall of the Jur has been recorded for the last few years. In 1901 it rose 2·7 metres between May 26th and September 16th, and fell 1·4 metres by 18th October.

MEAN RIVER GAUGE READINGS RECORDED AT WAU (IN METRES)

MONTHS	1904					1905				
	Mean*	Highest	Lowest	Average	Range	Mean*	Highest	Lowest	Average	Range
January	No observations previous to April 10th.					—0.23	—0·08	—0·32	—0·20	0·24
February . ..						—0.36	—0·31	—0·42	—0·36	0·11
March						—0·50	—0·43	—0·56	—0·50	0·13
April	[—0·09	—0·02	—0·18	—0·10	0·16]	—0·59	—0·53	—0·62	—0·58	0·09
May..	0·12	0·38	—0·09	0·14	0·47	—0·37	—0·17	—0·56	—0·36	0·39
June	0·37	0·87	0·12	0·50	0·75	—0·04	0·58	—0·33	0·12	0·91
July	2·11	3·02	0·86	1·94	2·16	0·53	1·32	0·18	0·75	1·14
August	8·54	4·04	3·07	8·56	0·97	1·18	1·70	0·20	0·95	1·50
September ..	3·10	3·96	2·26	3·11	1·70	2·08	2·39	1·75	2·07	0·64
October	1·96	2·92	1·56	2·24	1·36	2·10	2·87	1·45	2·16	1·42
November. ..	1·28	1·80	0·53	1·16	1·27	1·82	2·77	1·04	1·90	1·73
December ..	0·13	0·48	—0·11	0·18	0·59	0·49	1·02	0·07	0·54	0·95
YEAR Mean ..	[1·39	1·94	0·89	1·42	1·05]	0·51	0·93	0·16	0·54	0·77
YEAR Extreme	..	4·04	[—0·18	1·93	4·22]	..	2·87	—0·62	1·12	3·49
YEAR Date ..	..	Aug. 7	Apr. 13, 14 & 17	..	..	..	Oct. 29 and 30	Apr. 14, 20 & 22	..	..

* Mean derived from daily readings.

The Bongo is a smaller stream which flows in a northerly direction to join the Lol which in its turn flows to the Jur. The Bongo in January 1871 at Damuri (lat 8° N.) was found by Schweinfurth[2] to be only 15 metres wide and a metre deep, though in the rains it floods its banks and carries a considerable volume of water to the Jur.

Omitting numerous small khors there now remain only three main streams which flow from the western watershed to the Bahr el Ghazal; these are the Lol and the Kir which rise in the Faroge country to the west, and join respectively the Jur and the Bahr el Ghazal, and the Bahr el Arab, rising in the hills round Hofra el Nahas and having tributaries which come from Jebel Marra in Darfur, which flows into

[1] Schweinfurth, Pet. Mitt., 1872, p. 281.
[2] The Heart of Africa, II, p. 345.

the Bahr el Ghazal near the point where it turns north-eastwards towards lake No. The Lol is but little known in its upper reaches; crossed not far from its junction with the Jur[1] on December 9, 1904, it was about 180 metres wide, 5 metres deep with a strong current. The Kir about one hundred kilometres to the north of it, was 70 metres wide 3 metres deep with a slow current, a few days earlier..

The Bahr el Arab is a large river in the wet season; Felkin crossed it in December 1879 on about the 25th meridian and found its channel about 100 metres wide but there was little water in it and only a metre deep, while the banks rose about 4 metres above the water. Some 80 kilometres from its junction with the Bahr el Ghazal and before it enters the marshes it was in November 1904 from 70 to 120 metres wide and 1·5 to 2·4 metres deep, with a very feeble current. It here receives the Khor Keilak, some 70 kilometres long, which rises near Jebel Miri in southern Kordofan and after passing through a shallow lake flows southwards to join Bahr el Arab. Where this river joins the Bahr el Ghazal it has a well defined channel 80 to 100 metres wide, entering from the north but the direction soon turns westward and at a short distance up is blocked by vegetation.

We have then in this basin a number of larger streams besides many smaller khors, which drain the north-eastern slope of the Nile-Congo watershed and show a strongly marked periodicity. Most of them in March and April, at the end of the dry season, are almost dry in their middle and lower reaches, but when the rains set in they rise rapidly and flood their valleys, pouring a large volume of water into the level marsh plains through which they flow after entering their plain tract. Most of them near their sources are true mountain streams with rocky beds interrupted by rapids and small water-falls, but as soon as they reach the laterite plateau they cut out out a deeper channel which soon becomes a narrow steep-sided valley, in which both forest trees and smaller vegetation, grow with a luxuriance almost equal to that of a true tropical forest.[2] Here much water is taken up by the forest growth before the valley opens out into the narrow flood plains which border its stream, beyond which the wide plains of the marshes begin.

Even though the maps of this area are still very imperfect, they show in a striking manner a well-marked parallelism between the ridge which separates the tributaries of the Nile from those of the Congo on the

[1] Route Report, Dec. 1904, Percival.
[2] Schweinfurth, "The Heart of Africa," 1. p. 504.

south and the Kordofan-Borku ridge which extends to the mountains of Tibesti, while the high land of Jebel Marrah in Darfur joins the two and divides the basin of the Bahr el Ghazal from that of Lake Chad. At the present time almost no geological examination of this country has been made [1] so that all assumptions of earth movements are purely hypothetical. It is however remarkable that we have a low lying area with almost no slope lying between two higher ridges of crystalline rocks; the southern ridge shows a much steeper slope on its north face towards the Nile than on its southern or Congo face; the direction of it is parallel to that of the upper reach of the Bahr el Jebel from Nimule to Labore where a fault valley can hardly be doubted; so that it may be suggested as not impossible that the drainage line of the Bahr el Ghazal cutting, as it does, across the general slope of the country, is due to earth movement which has so tilted large blocks as to produce a lowlying area which intercepts the drainage and leads it eastwards. Owing to the fact that the northwest axis of movement was inclined to the general northerly slope of the country, the same change from mountain tract with rapids and waterfalls to valley tract where the stream has carved a well defined channel in the plateau, and finally to plain tract with low-lying areas flooded in the rainy seasons and often occupied permanently by swamps, occurs in each stream; but with the difference that the plain tract becomes longer and more important as we pass from the west to the east along the slope till it reaches its maximum development in the Bahr el Jebel.

To-day the part played by the Bahr el Ghazal in the regimen of the Nile is a wholly unimportant one, in spite of the very large quantities of water which this slope of the country pours into the marshy plains at its foot.

Knoblecher in December 1849 [2] says that the mouth of the Bahr el Ghazal could not be seen, so probably it was small. Petherick [3] gives it as 20 to 40 yards wide, 20 feet deep, and flowing a quarter of a mile an hour or 0·37 foot per second in December 1853. Brun Rollet [4] in February 1856 found it at its junction with lake No 50 to 60 metres wide including the reeds which occupied one-third of the channel; the depth varied from 3 to 4 metres. These data do not bear out the suggestion which has been made, that before 1860 the Bahr el Ghazal was much larger than it is to day.

1 But see Preumont in "Quart. Jour. Geol. Soc.," Aug. 1905, p. 641.
2 "Reise auf dem weissen Flusse, Klun," Laibach 1850, p. 11-13.
3 Egypt, the Sudan and Central Africa, 1861, p. 361.
4 Pet. Mitt. Erganzungsheft 7, 1862, p. 18.

Discharges have been measured on several occasions in the Bahr el Ghazal about 50 kilometres from Lake No with the following result:—

Date	Distance from lake No	Width	Sectional[1] area m²	Maximum depth	Mean velocity	Discharge
	kilometres	m.	m².	m.	m.p.s.	m³.p.s.
April 1, 1900... ..	51	79	161	4·3	0·211	34
„ 2, 1901... ...	33	84	149	4·0	0·181	27
„ 15, 1903... ...	50	84	200	4·4	0·195	23
Aug. 31, 1902... ...	33	49	86	7·2	0·172	15
„ 30, 1903... ...	28	70	52	5·3	0·231	12
Sept. 21, 1903... ...	32	70	104	5·3	0·192	20

De Malzac[2] on April 6, 1859 found it 179 metres wide at a point 200 metres upstream of lake No, 1·67 metres in average depth and flowing 0·607 metre per second, thus discharging 182 cubic metres per second, but this velocity is quite inadmissible. Petherick,[3] April 25, 1862, found its discharge to be 86 cubic metres per second by deducting his measured discharge of the Bahr el Jebel from that of the White Nile.

From these it appears that even in September only an insignificant amount of water passes. In November 1898 the rise of the water level at Meshra el Rek was only 22 centimetres above what it was in July, and in spite of the volume poured into the marshes by the Jur and other rivers[4] the velocity somewhat north of this was but 0·22 metre per second in September, though in the narrow channel further on it reached 0·55 metre. The maximum level in the Bahr el Ghazal is reached in November and December and as this is two months later than the flood of the Suei, the Wau and other tributaries, it is evident that it is the level of the flood in the Sobat which keeps up the level. For the present then the Bahr el Ghazal as a contributor to the Nile supply need not be taken into account since the quantity it furnishes is so small, and no change is to be anticipated, unless earth movements increase the slope of this part of the country, until the present swamps become filled with alluvial detritus and the grade of the river bed is thereby so modified that its waters flow in a defined channel instead of being lost as at present in the water-logged flood-plains.

Sir W. Willcocks[5] holds that its function at present is to keep wet the swamps between it and the Bahr el Jebel without which he considers

[1] The area of clear water in the section; the remainder is filled with reeds and grasses.
[2] Bull. Soc. Geog., Paris June, 1862.
[3] Proc. R. Geog. Soc., vol. VIII., p. 142.
[4] Dyé. Annales de Géographie, 15 July 1902.
[5] The Nile in 1904, p. 36.

that the waters of the latter stream would be lost by percolation in them and the White Nile would be left dry, but this is to misunderstand the regimen of the two streams. The Bahr el Ghazal drains off the surplus water which evaporation and absorption by vegetation have not removed, and if the supply was less, the swamps would become reduced in area; the Bahr el Jebel with a free flow down the White Nile would certainly not flow upstream to the marshes of the Bahr el Ghazal, at low stage though during the flood period of the Sobat, the low-lying area of the White Nile and lake No would be flooded as it is to-day.

The sadd. [1] —The accumulations of vegetable matter which from time to time block the channels of the Bahr el Zaraf, Bahr el Jebel, Bahr el Ghazal, the Jur, and the White Nile above its junction with the Sobat can form a serious obstacle to navigation and have to be taken into consideration in any scheme for the training of the rivers in this part of the Upper Nile.

From the difficulties which they have presented to expeditions such as Baker's in 1870-71, and the way in which they completely cut off Emin Pasha from communication with Khartoum and Egypt in 1878-80, these obstructions have come to be considered a strange and mysterious phenomenon of these rivers; their effect in holding back vast stores of water which would be set free once the sadd was removed has repeatedly been dwelt upon by writers who have not realised the conditions which prevail. The terrible experiences of Gessi Pasha, who with 500 men was blocked in the Bahr el Ghazal for three and a half months unable to force his way through until Marno came to his assistance, and released him when 400 out of 500 men had died and stores were exhausted, gave a vivid impression of the difficulties of dealing with these vegetable accumulations with no current to assist in their removal.

Marno[2] gives a good description of the "sadd" in the Bahr el Jebel which he was employed for many months in clearing, and points out that when the rainy season is of exceptional violence and long continued, the rivers which cannot even in ordinary years carry off the flood discharge, now overflow to form a flooded area of large extent.[3] Vegetation is carried by the wind and current out of the lagoons Into the river where it forms blocks in the sharp turns and

[1] Arabic سد sadd—to dam; in the interest of accurate terminology it is very desirable that the term "sadd" should be restricted to the block of vegetable matter in the river channel. It has of late been loosely used for the class of vegetation which grows in the swamps, the region of the swamps and even a type of country where swamps predominate.

[2] Pet. Mitt. 1881, p. 418-26.

[3] This statement has now to be slightly modified in view of the effect of the Sobat in flood, see Chap. IV.

narrow reaches, and the feeble current of the main stream has not the power to carry away these obstacles, but only brings down more and more material to add to it. By the increasing pressure of the dammed up waters of the river the mass becomes more and more compacted till it not only fills the breadth but even finally the whole depth of the river. It is only the buried and submerged grasses etc. which die, but those on the surface find themselves in specially favourable conditions for luxuriant growth, and their rootlets penetrate and bind together the mass in every direction. Thus a thick growth of grasses 2-3 metres high quickly forms, and if burnt down grows again within 8 or 10 days to a metre high in the rainy season. If such sadd blocks are of no great extent or thickness, the increasing pressure of the damned up stream may burst through them, but usually however the conditions which have caused one block have caused others in other parts, and the detached masses of the first blocks are therefore only carried down to add to the extent and density of another block. Such is the elasticity and density of these blocks that steamers have no effect on them, and cattle and even elephants can cross them. Where the action has far advanced the river bed is finally lost. While the vegetation in the blocks dies and decays, the silt with the vegetable materials and the roots forms a mass which is ever growing more and more dense; the grasses on the surface grow luxuriantly, the whole becomes at first a marsh, and finally is undistinguishable from the firm ground. The river has no longer any power to remove or break through the obstruction, but the water spreads into wide lagoons and finds its way by several smaller side channels to a point below the blocks. These channels gradually deepen themselves until one of them replaces the old channel as the main channel at this point. From this it would appear that those reaches where the breadth is least, the banks firmest and the windings most numerous, would be the most liable to sadd blocks. Thus from Lake No to Hellet Nuer these conditions are best fulfilled, and here occur the most numerous blocks though as will be seen there is another important factor, the Sobat flood, to be considered.

Much more definite information about the sadds is now available owing to the recent sadd cutting operations, and the results are summarized by Sir W. Garstin, who writes:[1]

"In the Bahr el Jebel the main component plants of the sadd blocks are the papyrus *Cyperus papyrus*, Linn. the "Bus" *Phragmites communis* and the "Um-suf" *Vossia procera* reeds; these three, with the earth adhering to their roots, form the real obstruction.

[1] Blue book Egypt 2, 1902 p. 34 and Report on upper Nile 1904 p. 109.

Many of the smaller swimming plants, such as *Azolla*, the *Utricularia*, and *Otellia* are mingled with the others; but they certainly do not play an important part in the formation of the obstacle. The Ambatch *Herminiera elaphroxylon*, Guill., too, has been unjustly accused of assisting in forming the barrier. This is not the case. This plant does not grow in any great quantity in the vicinity of the Bahr el Jebel, and its stem is so light and brittle, that it would break when subjected to great pressure."[1]

"On the Bahr el Ghazal, on the contrary, the "sadd" is chiefly composed of the swimming plants above mentioned. Their breeding places are Lake Ambadi, and the other shallow lakes to the south."

"The Ghazal "sadd" is much lighter in texture than that of the Bahr el Jebel, and is consequently much easier to remove. At the same time, even in the former river, the "sadd" is at times dangerous, especially if it forms, downstream of a vessel, and if the latter has to work upon it from its upstream end. The accident to Gessi Pasha's expedition in 1880, proves that even the Bahr el Ghazal "sadd" can be an impassable obstacle under such circumstances."

"The Bahr el Jebel traverses the marshes between Shambé and Lake No for some 400 kilometres of its course. South of Shambé, the river has never been known to be blocked. On either side of the channel, in these immense swamps, extend large shallow lagoons, some of them covering several square kilometres of area. The lagoons are surrounded on every side by a luxuriant growth of aquatic plants, consisting chiefly of the papyrus and the reeds known to the Arabs as as the "Um-suf" and the "Bus." All these plants grow in water, but not in any great depth, but the "Um-suf" and "Bus," will not stand such a depth of water as will the papyrus. This last attains a height of from 5 to 6 metres, with fibrous roots which strike deep into the ground. The "Um-suf" rarely exceeds two metres in height and its roots do not extend so deeply as do those of the papyrus. They are, however, very tough, and difficult to break or cut through. These roots are bedded in the soil below the water, but the strong gales which blow in these regions, loosen their hold to a large extent, so that if such a storm be accompanied by any rise of the water surface, large masses of these plants are set free from their original position, and begin to float on the surface of the lagoons. Their roots form such a tangled mass, that large quantities of the earth, in which they were embedded, remain clinging to them. These act as ballast, and when

[1] See also Hope. The Sadd of the Upper Nile. Annals of Botany Sept. 1902 and Broun Jour. Linn. Soc. July 1905.

the island of papyrus, or reeds, is detached, and, under the influence of the wind, is set drifting about the lagoon, the weight of this earth retains the plants in their vertical position. Their roots, the moment they reach a shallow, act as anchors, and speedily strike down again into the muddy bottom of the lake. Large masses constantly change their position in this way. If the storms cease, they remain where they are. Unfortunately, at the commencement and end of the rainy season, stormy weather is the rule, rather than the exception. At such seasons, large areas of the marsh vegetation are in motion, driven hither and thither by the wind."

"The channel of the Bahr el Jebel being only of sufficient section to carry the low-water supply, the first rise spreads over the marshes, flooding them in all directions, and increasing the depth of water in the lagoons. It thus causes the areas of reed, already detached by the wind, to float still more easily. A strong gale may set hundreds of acres of these floating masses moving in one direction, until they reach a point on the river where they are forced into the channel. Once there, the current speedily carries them downstream, and ere long, their course is arrested by a projection on the edge of the channel, or by a sharp bend. It may happen that an area of reed, several acres in extent, bursts into the river in a large sheet, and in such a case, it must necessarily be arrested at the first point where the section is contracted. The result is, that the channel is quickly blocked, though perhaps not at first to any great depth. Masses of weed, however, follow one another in succession, brought down by the stream. The section of the channel being reduced by the first obstruction, the velocity of the water rapidly increases, and these masses, following the easiest course, pass under the obstacle thus created. Each fresh mass arriving is sucked underneath those originally arrested, until at last the whole becomes wedged into one solid block, composed partly of earth, and partly of stalks and roots of papyrus and reed, broken up by the extreme compression, into an inextricable tangle. So great is the pressure applied by the water, that the surface of block is often forced several metres above the water-level, and is seamed by alternate ridges and furrows. The thickness varies greatly, according to the conditions and section of the channel. In some cases, it is not more than 1·5 to 2 metres, but it not infrequently attains a thickness of 5 metres, below water, and occasionally as much as 7· metres have been observed. Underneath this bar, the river manages to force an outlet, but with a velocity increased proportionately to the smallness of the aperture. At the same time, the upstream level rises, flooding the marshes in

every direction, the water making use of any side channel that it can find. In time, doubtless, if left to itself, it would desert its original course, and the stream would take an entirely new direction, the original channel becoming permanently blocked. It generally, however, happens from natural causes, such as strong winds, or increased heading-up of the water, that these blocks burst, and the obstacle is carried away. On such occasions, a great wave passes down the channel, carrying everything before it, and sweeping away any similar blocks which may have been formed downstream. Only in this way can the clearance of the "sadd" in certain years, which has undoubtedly occurred, be explained. Many of these blocks extend for a considerable length, some being as much as 1700 metres long. It is easy to understand, that such closures of the river channel, cause, not only a complete bar to navigation, but also a very serious obstacle to the free passage of the water. More than this, each block thus formed assists in the formation of others, by raising the water-level up-stream, and thus assisting the flotation of further areas of papyrus and reed, much of which eventually finds its way into the river."

At the time of the expedition of Mohammed Ali, 1840-1841, which Werne accompanied, no sadd was met with. The first account of it was received from Heuglin in 1863, who with the Tinné expedition found the White Nile blocked at a point 30 kilometres east of Lake No. An extensive lagoon on the south bank, afterwards known as the Maiya Signora, was followed and through it a way was found into the White Nile channel. This block was, it appears, avoided in this manner for some years till by about 1867 or 1868 it had so increased as to block this way also.[1] It was at first stated that the Shilluks had blocked the channel directly after the rains in order to prevent the passage of boats, but Heuglin says that for his part he could see no evidence of human handiwork in it. Against this obstruction the stream had piled up all the floating material day by day till a solid block was formed, which was estimated at about 500 paces (350-400 metres) long, and which was firm enough, except at a few places, for persons to walk over dryshod. The open water was 180 metres (250 paces) wide, and the water flowed over the barrier with a velocity of 3 to 4 metres per second. It was cut through in 2 days by a large number of men sufficiently to enable the boats to pass. Von Heuglin speaks of this as being at any rate a rare occurrence on the White Nile. (see Plate XI).

[1] Pet. Mitt. 1881 p. 420 and Pet. Mitt. Erganzungsheft 15, p. 16-17.

In 1865, at the end of March, Sir S.W. Baker[1] came to the same block and describes it as dangerous since the water rushed through beneath it and boats had at least on one occasion in 1864 been carried under by the current. The block was about 1200 metres wide, and perfectly firm, being overgrown with high reeds and grasses. In 1870 Sir S. Baker found the White Nile blocked in the same place and had to go up the Bahr el Zaraf,[2] but being stopped in lat. 7° 44′ N. had to return, and finally got through in the following year 1871.

In 1872 both the Bahr el Zaraf and the Bahr el Jebel were closed by blocks.

In 1873 Baker found no great difficulty in passing from Gondokoro down the Bahr el Jebel and thence down the Bahr el Zaraf.

During these years the Bahr el Zaraf was utilised although on account of the masses of vegetation and the shallow water in its upper reaches it was only passable with difficulty and for a short time after the rainy season. As these difficulties in the Bahr el Zaraf increased from year to year it was necessary to render the main stream navigable, and Ismail Pasha Ayub removed in 1874 the blocks in the White Nile and the Bahr el Jebel, and so opened again the clear waterway, but only with great difficulty.

In 1878[3] the unusually heavy rainy season produced an exceptional flood in the Nile and its tributaries, so much so that Lado, though situated on a piece of Land which was usually 5 metres above the ordinary water level, was half flooded. The first signs of sadd were found by Emin Pasha on his way from Fashoda to Lado in July, about 4 hours above the point where the Bahr el Jebel leaves Lake No.

On September 25, 1878 R. Buchta in going up the Bahr el Jebel met with sadd 50 kilometres north of Ghaba Shambe; also in February 1879 it was blocked[3] and remained so until it was cleared by Marno[4] in 1880.

In August two steamers sent up from Khartoum to Lado, only got through the increasing sadd blocks with the greatest difficulty, and one which left Lado on the 5th September had to return, being unable to pass the block which there was below the mouth of the Bahr el Zaraf.

In October a steamer going up from Khartoum got through, since it is easier to clear a way upstream than downstream, but after this all attempts at that time, October 1878 till September 1879, failed.[4]

On November 21 1878 Emin Pasha left Ghaba Shambe to see if

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[1] Albert Nyanza, p. 455-6.
[2] Ismailia I. p. 35.
[3] Pet. Mitt. 1881, p. 421.
[4] „ „ 1879, p. 273

it was possible to find a way down the Bahr el Jebel which was then blocked with sadd. The first block was some 8 kilometres below Ghaba Shambe, where the channel was completely blocked with vegetation for some 600 metres. It was possible to pass round it by making a long detour through lagoons and back channels. The second was about 8 kilometres above Hellet Nuer and blocked the river for a length of about 1200 metres, but this too was circumvented. The third block was in 4 parts and these occupied portions of the reach of the river from 55 to 75 kilometres from Lake No. The first of these blocks near Ghaba Shambe was in the same place that blocks 16-19 were found by Lieutenant Drury R.N. in January 1901.

When Marno, having cleared the block in the White Nile, went on to the Bahr el Jebel, he found no current at the mouth since the river was completely blocked. The northern end of Marno's 3rd block is given by him as 26·5 nautical miles (=49 kilometres) from the mouth of the river. It was exceptionally dense and large so that in some places the whole river bed, 5-7 metres deep, was filled by it. When the blocks had been removed there was a gradual sinking of the water in the river channel and in the lagoons beside it. From the latter water poured into the river by innumerable channels which were partially choked with mud and sunken grass islands. These the increased current raised to the surface and carried away, and gradually removed all the deposit which had been laid down in the main channel during the time that it had been blocked. After the removal of the 4th part of this No 3 block, the river seemed on March 27, 1880, free and open though with many stranded grass islands on the banks, and extensive lagoons which were in connection with the river. Above Hellet Nuer where formerly one followed round the sharp windings known as Ghursa el Kilab, there was a collection of wide lagoons, and the river, where it came from the NE., was blocked—the commencement of No. 2 block. Steaming through the lagoon towards the SE. a labyrinth of lagoons, canals and river arms was entered, and in one of these arms the current was exceptionally strong. It was soon evident that this was the new main channel, and it led back into the old channel from which point the southern end of No. 2 block could be seen at a short distance down stream, so that it included the Ghursa el Kilab. Since the current was carrying down with it masses of vegetation, and the channel was both narrow and with many sharp bends, this was a point where future blocks were likely to occur. It seemed that this reach of the river had altered greatly. In Werne's Map, north of lat. 8° N. the river is shown as dividing into two equal branches which afterwards

unite again, but in 1880 no such state of things could be traced. Still other maps (*e.g.* Pet. Mitt. Erganzunsheft 15) omit this fork and show only two bends cut across by side channels, which seems much more probable.

Near block 3 there was earlier a division of the river into a main channel and a side khor which thus included a small island. The main arm being blocked the river turned to the east, and scoured out the khor which thus became the main channel, while the island joined the west bank and became a part of it. It is interesting to see that on the above-mentioned map the Ghursa el Kilab, those sharp bends to the north at Baiderol (not the more northerly river bends which are wrongly named as Ghursa el Kilab)—is shown as cut across by a side channel approximately on the line of the new main channel of 1879.[1]

At the end of September 1879 the steamer "Bordein" returning from Lado brought the news of the sadd in the White Nile, and in the middle of November Marno went there from Fashoda to find the river blocked at a point between the so called "greater and lesser Ghaba el Kuk," 30 kilometres upstream of the Bahr el Zaraf. The amount of water brought down this year by the Bahr el Jebel had been large according to Marno and the White Nile here was much increased and so was in direct connection with the wide lagoons on its banks, but in the light of present knowledge this should rather be attributed to an unusually high flood in the Sobat. After the removal of this first block, Marno pushed on to see whether the rest of the White Nile was clear up to Lake No, and found there, where the sadd block had been in 1863-1872 and where he had removed one in November 1878, a new and very thick block some 250 metres long. The masses of vegetation were piled up to a thickness of 4-5 metres, the whole being compacted with mud and silt. This block had formed and had acquired its size and density within the short space of 70 days which had elapsed between the passage of the steamer "Bordein" and the arrival of Marno. As the main channel was almost completely closed by this block, the river had broken through its left (north) bank and found its way through a lagoon from which it had swept out all the floating vegetation and had gradually eroded a new bed, so that the blocked section could be avoided by using it. Here on a smaller scale were to be seen the same conditions as at Ghursa el Kilab.

It has been previously mentioned that the sand and silt brought down from the tributaries of the Bahr el Jebel are mostly deposited in

[1] Pet. Mitt., 1879, p. 273 ff.

the upper reaches near Bor; the amount of earthy material found forming a part of the sadd block must therefore be derived from the banks of the river which are eroded by any change of the current, and from that which is lifted from the bottom of the lagoons by the drifting vegetation. A sample of the sadd was taken from the west bank of the Bahr el Jebel at No. 9 block 108 kilometres upstream of lake No and was analyzed in 1900 at the Imperial Institute. The sample consisting of a damp dark-brown cake weighing about half a kilogram was a mixture of roots and stems of plants with mud, and on analysis gave the following results:—

	per cent
Water	57·21
Ash material dried at 105° C	64·69
Fixed Carbon	5·91
Volatile matter	29·4
Calorific value	1441 cals.

The comparatively short time during which the upper reaches of the White Nile have been known, does not allow us to say with certainty that no such obstructions occurred at earlier periods, although, according to Marno, the natives of these parts have no traditional knowledge of them. However the swamp conditions of these valleys have certainly been long in existence, and it can hardly be doubted that many of the lagoons and cut offs (ox-bow bends) are due to such interference with the free flow of the river causing it to erode a new channel for itself. The natives traverse the whole valley with ease in their "dugout" canoes or on their rafts of ambatch, passing along the narrow channels which intersect the marshes, and the blocking the main channel would be of no importance to them since they could readily pass round it.

Moreover, the records of the Roda Nilometer at Cairo show that all the floods but two between 1825 and 1840 were below the average, as were all except three from 1781 to 1800; [1] thus for a long time previously to 1840 the conditions were not favourable to the formation of sadd blocks.

The points at which sadd has blocked the river channel at various times are shown on Plate XI. The block which occurred in 1879 about 12 kilometres below Ghaba Shambe [1] is the most southern block recorded, while the next was at the sharp bend known as Ghursa el Kilab between Hellet Nuer and Maiya Kurshid, in the same place as the lower part of block 15 of the recent clearing opera-

[1] See Chap. VIII.

tions. The majority of the blocks seem always to have occurred in the last 150 kilometres of the river, so far as the available data go. The block which Miss Tinne's expedition met with in 1863 was about 30 kilometres east of lake No and this point was blocked more or less continuously from 1863 to 1874; in 1879 it was again blocked and having been cleared by Marno at the end of that year was again blocked in 1880, while occasional and temporary blocks have occurred east of the mouth of the Bahr el Zaraf. In 1870 Baker found the Bahr el Jebel blocked near its mouth, he passed into it about 30 kilometres higher up by a channel which communicated with the Maiya Signora; but again he found it blocked at a short distance higher up. Marno in November and December 1879 found the four parts of the third great block occupying some 15 kilometres of river.

These few years would seem to show that the northern portion of the Bahr el Jebel and the White Nile between it and the Sobat river is most subject to sadd and that the conditions favourable for the formation of sadd are (1) a rise of the water level, (2) stormy weather, (3) a narrow or sharply curving reach of the river. The rise of the water level in the upper reaches is probably due usually to heavy local rains, which will be all the more effective if the Albert lake is high and consequently a large volume is passing Wadelai, raising the general level throughout the valley (p. 76). In the lower reaches a high water level in the Sobat is probably the main factor, as on that depends the amount of flooding in Lake No and the Bahr el Jebel and Bahr el Ghazal. The weather is most stormy at the beginning and end of the rainy season, say in June and September, which are also the months of heavy rainfall, and these are probably the seasons when blocks are mostly liable to form, especially the autumn which coincides with the high water levels.

So far then as past experience goes sadd blocks are to be expected in years when rains on the southern tableland of Abyssinia are heavy and protracted causing a high and late maximum in the Sobat; 1878 and 1879 were especially years of this character and in these, as Marno has recorded, blocks formed rapidly and were of exceptional density.

Lombardini in 1865 [1] suggested that the area covered by the swamps of the Bahr el Jebel and the Bahr el Ghazal represented an ancient lake which had been silted up, and more recently Sir W. Willcocks, [2] has supported the hypothesis, for it is no more than this, and states

[1] L'essai sur l'hydrologie du Nil, p. 41, Milan, 1865.

[2] The Nile in 1904, p. 38, also Johnston. The Uganda Protectorate I, p. 151, London, 1904. and Brown. Jour. Linn. Soc. July 1905 p. 54.

that the lake measured 400 kilometres square, that it has since been filled by sand and peat deposits, that the Sobat river flowed into it, that the Blue Nile may have flowed into it up the bed of the present White Nile, and that the north-east corner of the lake has been better filled with deposit than any other part.

Beyond the fact that the slope of the country from Ghaba Shambe to Lake No is very low, and that there is much swamp from the Bahr el Zaraf to Meshra Rek, no evidence supports this lake hypothesis. On the other hand many facts are opposed to it. The probable mode of formation of these gently sloping plains has already been described (p. 91), but besides this there are other facts which do not agree with a lacustrine origin for the existing condition of things. The floor of a silted up lake is, but for subsequent earth movements, practically level, but here there is a moderate slope which recent levelling shows to be about 1 in 16,000 for the country west of the Bahr el Zaraf and the White Nile; below and above the Sobat junction it is 1 in 28,000 and 1 in 38,000 respectively at low stage.

Such a lake having its southern shore at Ghaba Shambe must have had its northern shore on the gently rising plain to the north of Lake No but no trace has yet been seen of any beaches or shore lines, which for a lake of such a size would have been strongly marked, nor do deltas of streams flowing into it occur. If its southern shore was at Ghaba Shambe it must also have extended some way up the present Sobat valley, but here again there is no trace of shore lines. In the lowest part of the lake, near Lake No, the soil is sandy, whereas is the centre of so large a lake only the finest mud would be deposited, and sandy deposits would be confined to the deltas of tributary streams. To turn the Blue Nile southwards into this lake the country from Shendy to Kodok must have sloped from north to south, instead of as to-day south to north and the altitude of the country in the neighbourhood of Shendy must have been some 80 metres more than at present in order to effect this; of such changes of level no evidence whatever has yet been brought forward. As the Atbara is assumed to have been at this time the sole supply of Egypt, [1] elevation cannot have affected its lower course, and a glance at the map will show that had such movements taken place in recent times between Khartoum and Berber clear evidence of it would exist to-day in this part, but none has been put forward and none exists so far as I can ascertain.

The Blue Nile, had it once flowed southwards into this hypothetical

[1] The Nile in 1904, p. 41.

lake, must have laid down large deposits of fine silt in this flat basin, but none occur. It is even stated that deposition was most marked at the north-eastern corner of this lake, and had this been the case the reversal of slope which allowed its waters to drain away to the north would have caused the river draining the lake to cut through these earlier deposits which would remain in the neighbourhood of Taufikia and Kodok as bluffs of alluvium. None however exist. The statement that "the White Nile channel of to-day is formed within the channel of old days when the Blue Nile was flowing south into the Sadd region"[1] is unintelligible since the slope would have been in the reverse direction and greater than to-day to carry the silt-charged waters of the Blue Nile, and therefore the original bed would have been in all the northern part high above the present valley, which on the assumed reversal of the drainage would have out cut been through the earlier deposits. But there is no need to assume such very localized movements; the whole of the present phenomena are easily explained by the low slope of an ancient flood plain formed from the material derived from the weathering of the plateau of crystalline rocks to the south and laid down by the numerous rivers which must have flowed from it. Except in the depressions and old river bends of the valleys where rank vegetation and local silting can hold back large quantities of water, the rapid evaporation during the period of the northerly winds removes the rain water that stands in the open country and reduces greatly the area of the swamps, but the Bahr el Jebel fed by the Albert lake, and the Bahr el Ghazal fed by numerous perennial streams from the Nile-Congo watershed are able to replace these losses sufficiently to prevent their swamps from drying fully, even in the driest years, while spills from the Bahr el Jebel in the neighbourhood of Ghaba Shambe do the same for the Bahr el Zaraf. The tributaries of the upper Sobat show the same since similar conditions occur there where no such lake could have existed.

On Plate XI the flood-plain, where the water surface is within 0·3 to 0·6 metre from the ground surface, is distinguished from the higher ground which lies beyond it and bounds the valley. This is about 1 metre and upwards above the water surface and on it grow acacia bushes, dom and deleb palms and some shrubs.[2] From this map it will readily be seen that the river is meandering through its flood plain, and swings from side to side of its valley as all low grade

[1] Loc. cit. p. 42.
[2] Broun, "Jour. Linn. Soc." July 1905, p. 53.

rivers do, while there is no sign of an ancient lake basin. The widest part of the valley is near Ghaba Shambe where the marshes fed partly by rainfall and partly from the Bahr el Jebel, are large enough to supply the Bahr el Zaraf throughout the year.

Summary.—In the basin drained by the Bahr el Jebel, the Bahr el Zaraf and the Bahr el Ghazal, the physical conditions are such that though it receives a fairly heavy rainfall, amounting yearly to about 1000 millimetres, as well as the 500 to 1000 cubic metres per second from the Albert lake, a constant supply of some 470 cubic metres per second is all that is available upstream of the Sobat junction.

At first there is a more or less steep slope from the southern plateau, soon ending in flat open alluvial plains on which the detritus eroded from the plateau has been laid down in remote ages. The present streams on reaching these plains of very low slope, change their character and become meandering rivers which deposit their load at once, and afterwards flow down their shallow valleys in which they swing periodically from side to side. But as they carry no silt their flood plains do not rise by the deposit of successive floods except at the head of this plain tract, and therefore the water surface stands but a very short distance below that of the flood-plain, so that there exist the conditions most favourable to the growth of marsh vegetation. This vegetation takes up a large amount of the water supply for its growth, and aided by the winds which blow for more than half the year from the bare savannah plains which lie to the north and east. Not only is the supply in the upper reaches of the rivers very greatly dimished bu the local rainfall only produces a temporary rise of level which evaporation and absorbtion soon reduce.

The net result then is that of the supply from the lake plateau delivered at the head of the Bahr el Jebel, only an amount equalling from 48 to 96 per cent[1] is available at the Sobat junction, in spite of the rainfall of the basin, while this constant supply above the Sobat junction is less that 1 % of the rain which falls on the Lake Plateau basin together with those of the Bahr el Jebel, Bahr el Zaraf and Bahr el Zaraf.

[1] 480 cubic metres per second above the Sobat junction compared with the 500 to 1000 discharged from the Albert lake,

SUPPLEMENT TO CHAPTER III.

THE BAHR EL ARAB.

During the past twelve months the officers of the Sudan Government have thrown considerable light on the relations of the different drainage lines which join the Bahr el Ghazal from the west.

Commandant Dyé in 1898 showed the Jur, formed by the junction of the Suei and the Wau, to flow eastwards through a low marshy tract to Meshra er Rek. North of this are two principal rivers, the Bahr el Homr and the Bahr el Arab, each with several tributaries more or less defined. The explorations of Lieut. Bayldon R. N. seem to establish that, contrary to the view hitherto held, the river rising to the south of Hofrat en Nahas and bending eastwards to the north of latitude 10° N. should be called the Bahr el Homr, while the more southern river, rising in the Dar Fertit hills to the west of Liffi, is the Bahr el Arab or Kir, which has the Lol or Lolli as a large tributary on its right bank in its lower reaches. This latter is to be distinguished from the Khor Lolle, which has a course parallel to the Nile above the Sobat junction.

It will be seen from the map that these two rivers, the Bahr el Homr and the Bahr el Arab, have a general direction at right angles to that of the Bahr el Jebel and, in consequence of the Nile-Congo watershed running in a north-westerly direction, they have a very short hill tract followed by a long plain tract traversing from west to east a vast plain of low slope which extends from the 23rd to the 32nd meridian, from the south of Darfur to the mouth of the Sobat, and lying between the slopes of the Bahr el Ghazal and the Bahr el Jebel basins on the South, and of the Darfur and Kordofan hills on the north. They are thus of low slope through most of their course. The Bahr el Homr (hitherto called the Bahr el Arab) rises in the hills to the south of Hofrat en Nahas while another branch comes from the Dar Minga country to the west. It is about 750 kilometres long from Hofrat en Nahas to its junction with the Bahr el Ghazal at a point 120 kilometres up stream of lake No, which is 132 kilometres above the junction of the White Nile and the Sobat river.

Measurements of the upper reaches are scarce; Felkin crossed it in December 1879 in long. 25° 20′ E. after a season of unusually heavy rain and found it to be 110 metres wide, with banks 4.5 metres high which are flooded in the rainy season, when the whole country is a vast swamp.

This point is about 500 kilometres above the junction with the Bahr el Ghazal.

About 70 kilometres from the Bahr el Ghazal, where crossed by Wilkinson Bey in January and December 1902, the river is 100 metres wide with water from 0.75 m. to 1 m. deep; some reaches are considerably wider and in these especially the surface is covered with grass and weeds.

South of this river, and generally parallel to it, is the Kir or Bahr el Arab, which receives the streams of the Dar Fertit hills though their junction with it is not accurately known. It joins the Bahr el Ghazal about 55 kilometres below Meshra er Rek at a point known as Ghabat el Arab, having received a considerable

tributary, the Lol, on its right bank, 60 kilometres higher up. Both these rivers, the Bahr el Homr and the Bahr el Arab, must closely resemble each other in their regimen.

Except in the region of their hill tributaries the rainfall must be moderate and the drainage lines from the north which descend from Jebel Marra in Darfur are said rarely if ever to carry water to them.

In the rainy season much of the level country through which they flow becomes an inundated swamp, since the slope of the rivers is very low. After the rains the country dries rapidly under the influence of the northerly winds blowing from the arid steppes of Darfur and Kordofan. Though no levelling has been executed in this region Dyé's observation that the high stage (rise of 22 cm.) at Meshra er Rek occurred at the end of November shows that the flood rise of the Sobat affects the river as far as this point, and consequently the last 60 or 70 kilometres of the Bahr el Homr and the Bahr el Arab, reducing the water slope to an extremely low value so that their waters flood the surrounding country to be evaporated in the early months of the year.

Therefore under normal tropical conditions of rains coinciding with the warm season, aided by slack current and long continued flooding due to the effect of the Sobat river, marsh vegetation can develope most favourably, and the blocking of the drainage lines is a natural consequence.

All who have visited these reaches lay stress upon the difference between the sadd in them and in the Bahr el Jebel.

While in the latter the vegetable material is swept into the river channel by storms, and is there packed by the current into masses of ever increasing density, that of the western region is described as much less compact. Marno speaks of the sadd of 1881 in the Bahr el Ghazal as composed mainly of grass which had to be cut and hauled on to the bank, and Broun saw the whole channel of the Bahr el Arab choked with the long rhizomes of the grasses *Panicum pyramidale* and *Phragmites communis*. The sadd of the Bahr el Jebel and the Bahr el Ghazal systems is thus essentially different in both character and origin. In the first vegetation is drifted by storms from lagoons into an ordinarily clear river channel, in the second it grows mainly in the channel and receives only some additional material from side khors and lagoons; the first is abnormal and re-appears only with the special conditions which caused it, the second is normal and is developed more or less with each rainy season. As supply channels the Bahr el Homr and the Bahr el Arab seem most unpromising. Let us suppose that both channels are free from vegetation, and trace their annual regimen.

In February, March and April they are at their lowest, and their contributions to the Bahr el Ghazal can be but small. In May the Sobat commences to rise and also the western tributaries of the Bahr el Ghazal; by July and August the Sobat has probably risen 2 to 3 metres and the up-stream water slope is much reduced. The critical stage is soon reached, so that the up-stream levels rise almost equally with that of the Sobat. Any slight rise in this level basin means excessive flooding and great loss by evaporation for there does not exist even so shallow a valley trough as that between Khartoum and Dueim. There 1,500 million cubic metres are stored annually for 2 or 3 months and it forms a useful though wasteful reservoir.

In the lower reaches of the Bahr el Ghazal system no such trough exists, and flooding is controlled.

CHAPTER IV.

THE SOBAT RIVER.

The basin of the Sobat is about 244,900 square kilometres in area, less than half the size of that of the Bahr el Ghazal, but the part played by this catchment area in the economy of the Nile is an important one. The northern boundary is not well defined but may be considered as approximating to an east and west line through the station of Taufikia as far as the head waters of the Sonka river in the hills of the Lega Gallas; from this point the watershed between the Sobat and the Blue Nile runs south-east to the Seshia mountains near Shalla, a village between the head waters of the Baro and the Didessa. It now continues slightly west of south for some 200 kilometres and then turns westwards between the districts of Boma and Musha and on to the open plains which lie east of the Bahr el Jebel and south of the spurs and outlying hills of the equatorial plateau. The dividing line from this point between the Sobat and Bahr el Jebel basin on the western side is very ill-defined as part of the rainfall probably drains to the Bahr el Zaraf and part to the Sobat by the Pibor and Khor Filus, but by far the greater portion evaporates; to the south the mountain streams in flood pour down on to these plains and their waters also evaporate eventually, except the small portion which reaches one or other of the tributaries draining these plains to the north.

The Sobat is formed by a number of rivers all of which drain the table-land of Kaffa except the Pibor which comes from the open plains to the east of the Bahr el Jebel. Of the others the Akobo, the Gelo and the Bela join the Pibor, while the Baro receives the Birbir, the Almo, and the Sonka, and joins the Pibor some kilometres above Nasser to form the Sobat.

Here we meet for the first time the Abyssinian table-land which reaches an altitude of 2000 to 2500 metres near the source of the Akobo and about 2000 metres at Gore and 2100 at Shalla near the head waters of the Baro, while the plain at the foot of the hills does not usually exceed 800 metres. Granite appears among the lower foot-hills near the Akobo river, while volcanic rocks (basalt) overlie it.[1]

On leaving the foot-hills of the plateau the Baro is about 200 metres

[1] Jessen, "Geog. Jour.," Feb. 1905, p. 168.

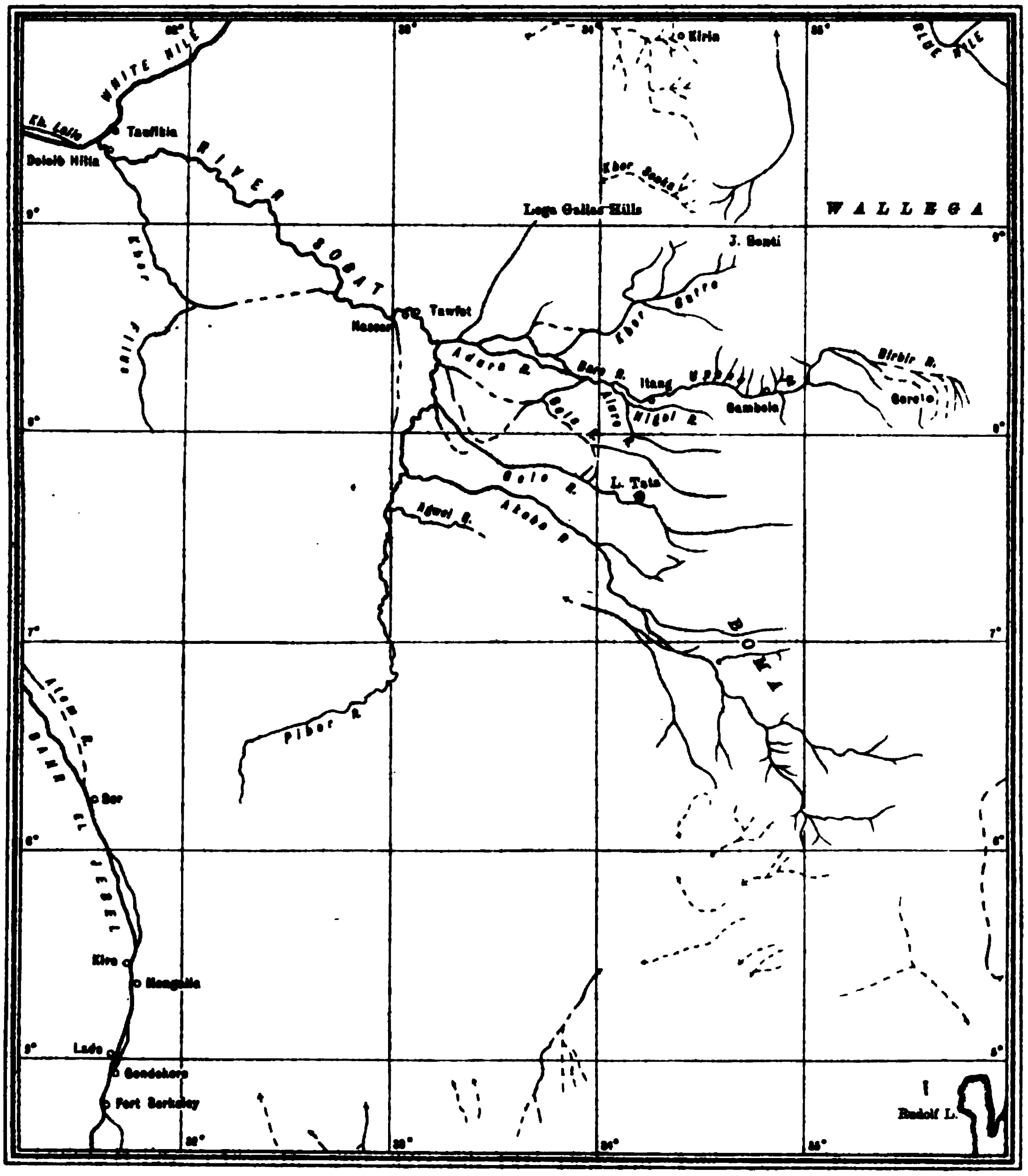
wide with high wooded banks as far as Itang; beyond this swampy flats occur where tributary streams like the Nigol, the Tokau and others join it; the main stream is now in its plain tract and flows in wide curves occasionally bifurcating so as to include large islands between its branches. The largest of these is above the Pibor junction where the southern arm is known as the Adura, a stream some 100 metres wide which includes an island some 50 kilometres long between it and the Baro. Below the Pibor junction the river, now known as the Sobat, flows in meander curves between banks on either side of which park land alternates with open grass plains; islands occur here and there in wider reaches but usually it is in a single channel from 100 to 120 metres wide. Behind the banks, which are usually higher than the flood rise of the river, there are often low depressions which are filled with water in the rainy season and continue to exist as swamps for some months, being drained off later by the natives through cuts in the banks in order to capture the fish in them. Just before the Sobat meets the White Nile the Khor Filus comes in on the left.

Climate.—The climate of the Sobat basin presents several varieties, which range from that of Doleib Hilla close to the junction with the White Nile with almost Saharan conditions of high temperature, wide range, and great dryness in the dry season, to the mild climate of the Abyssinian plateau where the temperature varies but little. The plains probably approximate closely to the conditions recorded at Doleib Hilla, with a somewhat longer rainy season in the southern parts. The winds are north and north-east in the dry season and southerly during the rains, but close to and on the plateau the diurnal variation between mountain and valley winds doubtless affects the general direction and causes the westerly winds, which were observed at Gore by Michel in the rainy season. It seems most likely that this Kaffa-Wallega plateau receives the heaviest rainfall of Abyssinia since the southerly winds blow against this high table-land for about five months of the year.

Doleib Hilla.—Sept. 1902-Dec. 1904.

Temperature Centigrade	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Mean monthly..	21·0	25·4	24·5	29·4	26·4	24·1	23·0	23·2	24·0	23·7	22·9	21·4	24·1
Mean daily maximum	36·6	33·6	38·8	39·9	34·6	32·7	30·1	30 5	32·8	33·5	36·0	35·6	34·6
Mean daily minimum	18·2	18·2	20·5	23·4	22·2	21·0	20·4	20·6	20·0	19·4	18·6	17·2	20·0
Range..	18·4	15·4	18·3	16·5	12·4	11·7	9·7	9·9	12·8	14·1	17·4	18·4	14·6
Extreme maximum.	38·9	40·3	43·8	42·9	39·8	37·4	34·7	34·7	36·2	37·3	38·0	38·6	38·6
Extreme minimum	15·5	14·5	17·5	20·1	20·1	18·7	18·7	18·5	19·0	18·0	15·5	14·2	17·5

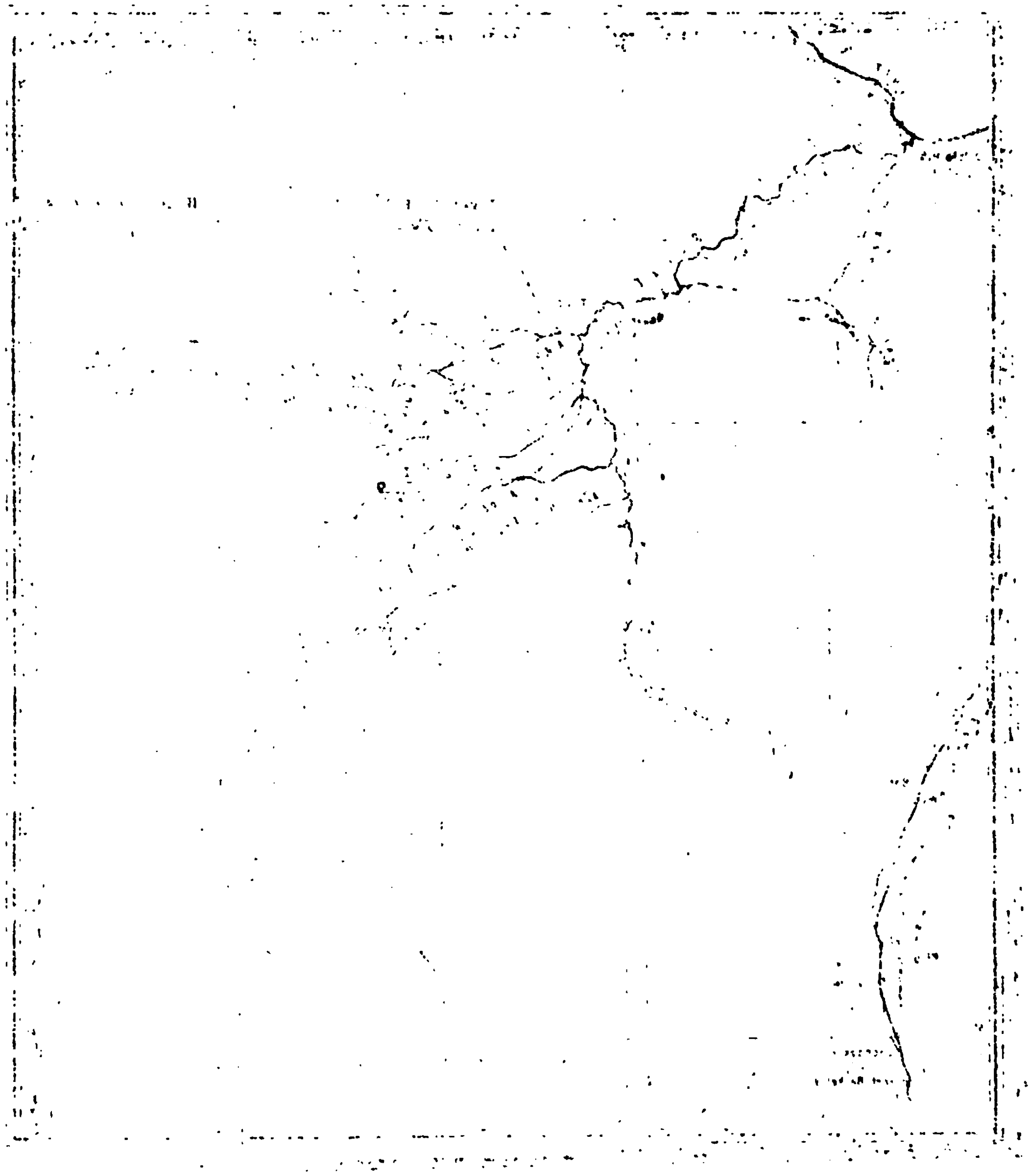
THE BASIN OF THE SOBAT RIVER



Scale $\frac{1}{4,000,000}$

Km. 50 40 30 20 10 0 50 100 150 200 Km.

Miles 50 40 30 20 10 0 50 100 Miles



Doleib Hilla.

Percentage frequency of winds September 1903 to December 1904.
(Usually 2 observations daily.)

Month	N	NE	E	SE	S	SW	W	NW	Calm
January ..	74	16	..	..	5	2	..	3	..
February ..	82	2	..	..	10	4	1	1	..
March.. ..	39	11	1	10	16	12	3	8	..
April	11	15	6	18	13	9	18	10	..
May	3	2	11	13	34	13	16	2	6
June	5	2	13	27	23	13	17	..	..
July	..	5	11	19	24	18	15	..	8
August ..	2	3	16	19	23	15	16	..	6
September ..	29	5	..	3	60	1	2	..	..
October ..	24	8	6	10	27	9	10	..	6
November ..	61	12	3	5	12	2	3	..	2
December ..	82	10	..	..	6	..	..	2	..

RAINFALL IN MILLIMETRES.

Doleib Hilla.—altitude 395 metres.

Date	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1903	..	..	..	..	66	150	171	163	177	172	40	0	[939]
1904	0	0	47	62	101	132	186	153	78	30	9	0	798
1905	0	0	4	2	92	82	109	131	153	48	69	0	690
Mean	0	0	26	32	86	121	155	149	136	83	39	0	827

Nasser.—Altitude 470 metres (approx.)

Date	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1903	..	..	..	..	..	..	..	..	..	50	0	0	[50]
1904	1	0	27	7	118	152	210	236	74	34	21	0	880
1905	2	0	0	22	44	162	82	152	120	67	18	0	669
Mean	2	0	14	14	81	157	146	194	97	50	13	0	768

Mean Rainfall in Millimetres.

Place	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Doleib Hilla.	0	0	26	32	86	121	155	149	136	83	39	0	827
Nasser	2	0	14	14	81	157	146	194	97	50	13	0	768
Gore ..	..	..	r	R	R	*R*	*R*	*R*	*R*	r	..	..	..
Shalla	..	r	r	R	R	*R*	*R*	*R*	*R*	r	..	..	..
Wallega	..	..	r	R	R	*R*	*R*	*R*	*R*	r	..	..	..
Beni Shangul	..	..	..	r	R	*R*	*R*	*R*	*R*	r	..	..	..

r = Light rain. R = Moderate rain. *R* = Heavy rain.

As already mentioned[1] the Abyssinian rainfall is due to the moist air of the south-east trade wind coming in contact with the elevated mass of the Abyssinian plateau 2000 to 2500 metres above the sea, where its moisture is condensed and falls as rain. This is especially marked in the southern half of Abyssinia, as here the rain is said to be heavier and more continuous than in the north where the southerly winds are weaker and have already lost much of their moisture.

Commencing with the district of Kaffa, Gore (2160 metres) is an Abyssinian frontier town on the south-western extremity of the Kaffa plateau above the valley of the Baro river. Austin[2] states that when he was there on March 12, 1900, the early light rains were said to be already overdue. Later, on the 1st May, when on the plains south-west of Gore and to the south of Baro river on the banks of the Gelo he experienced[3] heavy rains, while at Nasser at the junction of the Baro and Pibor rivers in the same year the river Sobat rose 3·5 metres between the 7th and 24th June and by the end of June was high.[4]

At Moger (lat. 8° 18′ N., alt. 2160 metres), between the head-waters of the Guder and the Omo, Cecchi[5] in 1878 recorded rain as follows:—

	July	August	September	October
Rainy days	22	27	22	6
Days of observations	29	31	29	28

The rain of July, and especially August, was heavy while that which fell in September was much lighter. In the spring and summer of 1879 he was at Shalla (lat. 7° 44′ N., alt. 2070 metres) and there the results were:—

	Feb.	Mar.	April	May	June	July	Aug.	Sept.
Rainy days	1	8	6	10	6	24	23	23
Days of observations ...	5	16	9	24	9	31	31	29

In 1897 and 1898 the Bonchamps expedition was for some time in this part of the country and on the plateau which divides the tributaries of the Abai from those of the Omo and Hawash. Michel,[6] who accompanied the expedition, reached Gore in June 1897 and experienced heavy rains until he left at the end of August in the middle of the wet season to return to Addis Abbaba. He considers that the rainy season proper in these parts commences about the middle of June and lasts until the beginning of October, the remainder of the year

[1] Ch. I.
[2] Among swamps and Giants, London 1902. p. 34.
[3] Ibid. p. 46.
[4] Ibid. p. 52.
[5] "Da Zeila alle frontiere del Caffa," Rome, 1887.
[6] "Vers Fachoda," Paris 1901, pp. 530 and 537.

being dry. He adds that on these plateaux of Abyssinia there is about 20 days rain at the end of February, and in March, April and May some 3 or 4 falls of rain occur each month; the end of May is marked by frequent thunderstorms which herald the rainy season. Though it is not specially stated, it is presumably the Wallega plateau south of the Abai which is specially referred to as M. Michel traversed this four times. At first in the daily thunderstorms rain falls during 3 or 4 hours each afternoon; by the 15th of June the rain increases and falls also at night, and increasing throughout July it is practically continuous during August and September. The wind here (in the neighbourhood of Bure and Gore) in the rainy season is from the west, and from the north-east in the dry season. For 1-20 July, 1897, the mean minimum temperature at Gore was 10° 8′ and the mean maximum 24° 2′.

Since this south Abyssinian plateau supplies the Didessa, and other southern tributaries of the Abai the rainfall in this part is of great importance to the Nile flood. Plowden [1] states that the rains in Gojam begin in June and end only in October being about a month earlier and a month later than in Amhara and Tigre.

On the plateau of the Lega Galla country, to the west of Addis Abbaba, Major Gwynn noted in February 1900 that the prevalent wind was from the SW. and usually light. This is probably only the valley wind blowing up from the plain to the higher plateau, since at this season of the year the north winds extend as far as latitude 4° N. at least. The natives stated that the light rains began here about the end of March, and continued till the beginning of June with gradually diminishing intervals of fine weather. The heavy rains commence with June. In 1903 at the end of May the rains were already setting in at Nasser and the Baro had risen considerably but irregularly near Itang as successive freshets came down, showing that the continuous rains of the wet season had not yet fully set in. By the third week of June the cloud zone ceased 30 kilometres north of Renk, in latitude 12° N. on the White Nile, and from Jebelein northwards the weather was completely different from that further south being hot and dry with clear skies. Major Gwynn also records that at the beginning of April 1901 at Aroji on the west side of the Didessa river rain fell heavily both by day, and also by night, for about a week while he was marching through the Wallega district and the country showed signs of rain having previously fallen as there was already a considerable growth of young grass. At the same time Captain Smythe experienced very heavy

[1] Abyssinia and the Galla Country, London, p. 28.

rain at Kirin in Beni Shangul, which caused floods in all the khors. It was these rains which caused the slight rise of the Nile from the 11th to the 25th of April at Roseires in this year, and affected at the Wadi Halfa gauge in the middle and end of May.

Early in May 1901 Major Gwynn noticed that heavy clouds hung over the plateau of Beni Shangul, but at Famaka on the Blue Nile and to the north of it the sky was clear and no rain has yet fallen, though there had been a good deal in Beni Shangul; but about the middle of May the rains passed to the north of the Blue Nile, and by the 25th the rise of the river at Roseires set in.

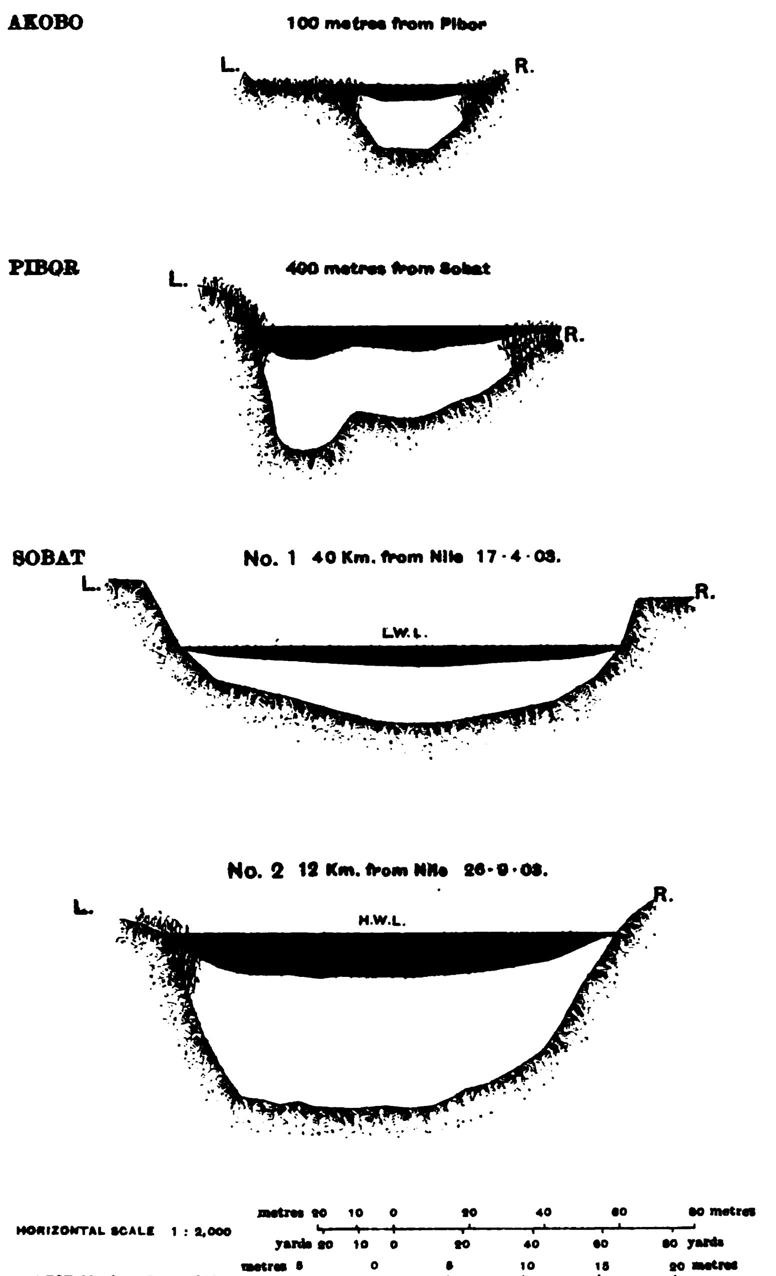
Thus in the districts of Kaffa, Wallega, and Beni Shangul, the rainy season opens with light rains between the middle and end of March. These continue throughout April and May gradually increasing in frequency till they merge into the heavy rains which are considered to set in at the beginning of June.

Hydrography.—The Sobat differs in its regimen from most of the other rivers of the Nile basin since it is lowest at the end of April and then rises slowly but steadily till the end of November, when it reaches its maximum, after which it falls rather rapidly. Gauges exist at the American Mission at Doleib Hilla, about 36 kilometres from its junction with the White Nile, and at Nasser 275 kilometres upstream, but the latter is not wholly satisfactory since it is not yet clear whether the same gauge has been used throughout. The cause of the steady rise and fall of the lower Sobat is to be found partly in the wide extent of the western Abyssinian plateau from lat. 6° N. to lat. 9°½ N., a length of about 400 kilometres, which is drained by the streams which flow to the main river but more in the flooding of the plains south of Baro, and the long course of low slope from the mountain foot to the White Nile. The rains on this plateau fall, as has been said, from March to October while the plains at the foot of the hills are flooded by the heavy August and September rains. Commencing on the north there is the Sonka river which rises in Jebel Senti (1900 metres) in the country of the Lega Gallas and flows west and then south joining the Baro 30 kilometres up-stream of Nasser. Next a number of small streams form the Khor Garre or Tokau which joins the Baro about halfway between Itang and Nasser.

The Baro itself, the main tributary of the Sobat, has been followed as far as 3 km. above its junction with the Birbir[1] where it flows through

[1] 560 kilometres from the mouth of the Sobat.

SECTIONS OF THE SOBAT, PIBOR, AND AKOBO RIVERS



SURVEY DEPT.

PLATE XV

SECTIONS OF THE SOBAT, PIBOR AND AKOBO RIVERS

SURVEY DEPT

a deep gorge, in a bed 40 to 60 metres wide, having a rocky bottom which formed a series of rapids in February.[1] Beyond this point the exact line of the valley is not known but it rises in the Seshia hills near Shalla which is situated at an altitude of 2070 metres,[2] about 750 kilometres from the White Nile.

After the junction with the Birbir low rocky hills approach the banks which are thickly wooded, and numerous stream beds meet the main stream, but in February these are all dry except the Bongo which comes in on the left bank, and is described by Austin (February 1899) as being 15 to 20 yards wide and 6-9 inches deep.

The river in this reach is known as the Upeno. By the time it reaches the village of Itang the woods cease and open grass country extends along the right bank while on the left grass plains alternate with marshes. The river Baro is here 230 metres wide. At this point the tributary stream Nigol or Aluro is only 3 km. distant from the left bank, its bed, which is about 36 metres wide, was dry in April 1899 but Austin remarks that in flood time it may be an important stream perhaps 60 metres wide.

South of this all the rivers flow to the Pibor except the Aluro and one or two smaller ones which lose themselves in the swampy depressions. The Aluro where it turns northwards was found in April to be 7 metres wide and breast deep [3] while about 30 kilometres higher up it was 10 metres wide and 1 metre deep in May, which increased in June to 20 metres wide and 3 metres deep with a strong current;[4] the Bela or Nikani seems neither to reach the plateau nor to be of any importance.

The Gelo rises in the Shekko district of south-western Abyssinia [5] and here flows through the densest forest, finally breaking through a gap in the mountains in a series of magnificent cascades; on leaving the Abyssinian hills the country becomes increasingly flat and swampy until it flows by Lake Tata. The Gelo is described as a "mighty river" in its upper reaches and it is due to loss of its water in the numerous swamps that by the time it reaches the Pibor in lat. 8° 8′ it has dwindled to moderate dimensions. At this point in May 1900 it was 25 to 35 metres wide with a swift current. [6] It is still a large stream 80 to 100 metres wide below lake Tata, while 30 kilometres

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[1] I.D.W.O., map N° 1489 sheet 66 P.
[2] Cecchi, vol. III., p. 531.
[3] Austin, "Geog. Jour.," May 1901.
[4] Jessen, "Geog. Jour.," Feb. 1905.
[5] Neumann, "Geog. Jour.," Oct. 1902.
[6] Geog. Jour., May 1901.

higher up it was in May 30 to 80 metres wide 1 to 3 metres deep, flowing between banks 6 to 9 metres high at the rate of about 1·3 metres per second; in June it was 5 to 6 metres deep with a strong current.[1]

The Akobo, which is the most important tributary of the Pibor, rises in the highlands of Kaffa in lat. 6° 30′ N. at an altitude of about 900 metres and after a course of about 90 kilometres it is joined by the Kaia; above this point the Akobo is 10 to 25 metres wide and flows rapidly with a depth of from 1 to 3 metres[2] (May); the Kaia contains but little water at this time but would seem to be a considerable stream in the rains. Further down the Akobo is at first 60 metres in breadth but later it decreases to 25 or 30. Nearly all these tributaries rise in the Kaffa highlands where the rainfall is both heavy and prolonged, and therefore they must bring down a considerable amount of sand and silt in suspension, which is mostly deposited when the velocity of the stream is checked on meeting the level plains. Thus at a distance of 60 or 70 kilometres from the plateau the slope of the country has become very flat and wide swampy tracts occur which drain into the rivers by means of the short streams which lead from them; the rivers become meandering streams flowing in well defined channels cut in the level surface of the plain. In the rains the whole of this country is flooded and gradually drains off as the rivers fall. The Pibor receives these streams in the open plains which lie to the east of the Bahr el Jebel, and when recently (July 1904) it was explored, it was found some 50 kilometres east of Bor to be a narrow water channel 20 metres wide and 1 metre deep in a vast extent of flooded country where the water was then from 0·30 to 0·50 metre deep. The channel was 15 to 20 metres wide occasionally widening to 50 metres, and had at first a northerly then north-easterly direction; the depth was usually from 4 to 6 metres and well defined banks only begin some 25 kilometres above its junction with the Agwei river; the current is said to be about 0·3 metre to 0·5 metre per second.

Its tributary the Agwei is described as flowing between banks 1 metre high, with an average breadth of 30 metres and a depth of 6 metres at the end of August the velocity being estimated at about 0·5 metre per second. Though the Pibor receives so many streams in an area of heavy rainfall, the volume which it supplies to the Sobat does not seem to be large; it was measured in October 1901 by Captain Wilson at point just above the junction of the Akobo river and found to be 70 cubic metres per second, the depth being 4·5 metres. The

[1] Jessen, loc. cit.
[2] Jessen, loc. cit.

Akobo on about the same date was discharging only 10 cubic metres per second though the clear waterway was 15 metres wide and 4·5 metres deep, the whole width including reeds being 60 metres. (Plate XIV).

The plains of the Upper Sobat therefore are a wide expanse of level country through which a number of streams meander in usually well defined and deep channels. The rains which begin on the plateau in March and on the plains in May become very heavy in July, August and September, and last into October, causing the rivers to overflow their banks and flood the plains. Though much of this is lost by evaporation still a considerable quantity flows into the Sobat and keeps up its level till the end of November. It is incorrect to say that the tributaries meet and form extensive swamps from which the Sobat has its origin, [1] since the Baro and Sobat form a clear and continuous waterway, while the Pibor joins the Baro direct and is joined in the same way by its own tributaries; the swamps are formed by the rivers overflowing their banks in the rainy season but they all have well defined beds and the moderate volume discharged is due to the low slope and the occasional blocking of the channels by vegetation, rather than to swamps or lagoons receiving their waters. So long as the Baro is high the water-slope of the Pibor must be very slight, but when the former river falls, the discharge of the Pibor becomes considerable. The only lake in the plain tract of these rivers is the small lake Tata, which is connected with the Gelo river but does not form a basin into which the river flows. [2]

Below its junction with the Pibor the Sobat maintains a width of 100 to 150 metres, occasionally in the neighbourhood of islands reaching 300 metres. It has a deep section and high well defined banks which are only inundated in the upper reaches, and beyond these there lies usually a belt, more or less continuous, of low-lying land which becomes a series of swamps on the commencement of the rainy season. Beyond the swamps is the higher park-like country with scattered villages.

Near the junction with the White Nile it is joined by the Khor Filus from the south. This Khor 30 to 40 metres wide, has been followed[3] as far south as lat. 8° N. a distance of about 130 kilometres from the Sobat and beyond this it was stated by the natives to be connected with the Bahr el Jebel in the neighbourhood of Bor. The channel widens in places to 70 and 80 metres but is always much choked by weeds, etc.; in August 1902 no appreciable current existed in this khor so far as a steamer could penetrate. It appears to be, like the upper

[1] The Nile in 1904, Cairo, 1905, p. 37
[2] Jessen, "Geog. Jour.," Feb. 1905.
[3] Cap. H, Wilson "Geog. Jour," October 1902.

Pibor, a water channel which is too much blocked by vegetable growth to be of any practical importance, though acting as a drainage line to a moderate degree.

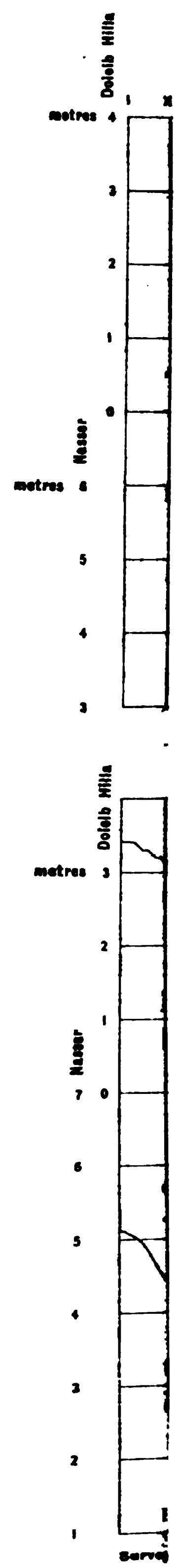
From the foregoing details it is possible to form a fairly complete idea of the regimen of the Sobat basin. The rainfall of the Abyssinian plateau is carried off by a number of streams flowing down deeply eroded valleys whose high slope and narrow sections mark them as young in development. At the end of March with the early rains these streams rise, but the effect is not felt far and it is not till May that their flood waters begin to affect the lower reaches. These mountain streams in falling from altitudes of about 2000 metres on the plateau to about 600 to 800 metres on the plains at the foot of it, must do a great amount of erosive work, charging the flood waters with sand and mud but as they all enter a gently sloping alluvial plain on leaving the hills the greater part of their load must be deposited before it has been carried far. The consequence of this is that the beds of these streams are rapidly raised by the deposit of material which the stream has no longer the power to transport on account of its reduced velocity, and therefore the waters spread over the banks, converting the plains into marshes or inundated areas. The Baro increased by the Birbir and other tributaries follows a direct course to the Sobat and thus retains its velocity better than streams like the Akobo, the Gelo, and others which meander through the alluvial plain for a greater distance consequently it is the principal factor in raising the level of the lower Sobat. This stream rising rapidly in flood checks the flow of Pibor by raising the water level at the junction so that the large flooded area through which the Pibor, the Akobo and the Gelo flow cannot be drained till the Baro begins to fall at the end of the summer.

Of these streams in their mountain tract very scanty data exist, Michel[1] gives a few for the Birbir and the Baro which are of considerable interest and are here reproduced.

The Baro was measured above its junction with the Birbir, and consequently before it left the hills, with the following results:—

	Low Water (March)		High Water (July, Aug.)	
	Deep channel	Total	Deep channel	Total
	metres	metres	metres	metres
Width	6	8	8	11
Depth	3	..	6·5	..
Velocity per second	1·25	..	4·5	..

[1] "Vers Fachoda," Paris 1901, p. 558.


Doleib Hills
metres
Nasser
metres
Doleib Hills
metres
Nasser

this would give approximately a volume of 300 cubic metres per second discharged at high stage and about 30 cubic metres at low stage.

The Birbir was also measured near its junction with the Baro :—

	Low Water (March)		High Water (July, Aug.)	
	Deep channel	Total	Deep channel	Total
	metres	metres	metres	metres
Width	4·5	16	12	19
Depth	3·5	..	6·6	..
Velocity per second	4·0	..	4·5	..

corresponding approximately to a volume of 450 cubic metres per second in flood and to 120 cubic metres at low stage.

He says that these rivers rise at the beginning of June and are at highest stage in July and August, low water being from January to May.

On November 11, 1904, Captain Wilson found the Birbir some kilometers above the junction 73 metres wide, about 4 in mean depth and flowing 2 to 2·5 metres per second. This would correspond to a discharge of about 600 cubic metres per second.

Without doubt then the Baro increased by the Birbir is the main supply of the Sobat and by its steady flood-rise in June, July and August followed by a period when it stands at a high level, it checks the flow-off of the Pibor and its tributaries thereby contributing to the flooding of the plains south of the Baro. The Pibor and Akobo[1] discharged respectively 70 and 10 cubic metres per second in October but in December this increases when the Sobat is falling.

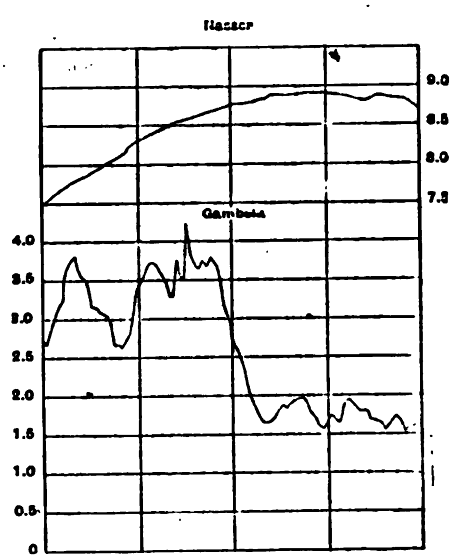
Below the junction with the Pibor the Sobat flows in the well-defined channel which it has cut in the alluvial plain, meandering in numerous curves. In April it is at the lowest level though in some years slight temporary rises occur, but in the first half of May an increase is noticeable usually becoming a steady rise before the end of the month and this continues at a gradually diminishing rate until the end of September.[2] The fall begins in November or December at Doleib Hilla according to the strength or weakness of the autumn rains on the plateau of Abyssinia, and in 1904 it began exceptionally early. The gauge at Nasser shows a decrease one month earlier than at Doleib Hilla but the gauge at the former place is as yet uncertain, for it seems that in high flood a second gauge near the fort had to be used, since the river-bank is flooded and the correlation of these two scales is open

[1] Measured by Captain H. Wilson at the end of Oct. 1901. (Plate XIV).

[2] See Plate XV.

to doubt. This slow rise, the long period of high stage, lasting from 3 to 3½ months and the rapid fall distinguishes the Sobat from all other tributaries of the Nile, except perhaps the Didessa which rises near it (see p. 144). The causes which produce these characters are, firstly the early rains of April and May which gradually increase to the maximum of the heavy rains in August, secondly the long continuance of the rains due to the southerly position of the district of Kaffa which keeps up the supply of the streams longer than in more northern districts, and finally the inundated flood plains of the southern tributaries are drained off in November or December resulting in the rapid fall of the Sobat.

The long plain tract traversed by the Sobat and its tributaries smooths all the sharp variations in level which they show in their mountain tract; and in the diagram the regulating effect of the flooded Pibor plains is well seen by the difference between the rapid fall of the Baro at Gambela (540 kilometres from the White Nile) in the end of September, while Sobat in its lower reaches continues to rise for one or even two months more.



The discharge of the Sobat has been measured on numerous occasions. Werne[1] records December 8, 1840, that the mouth of the Sobat may be 500 paces wide, the depth 6 fathoms and the velocity 2 miles per hour

[1] The White Nile, vol. I., p. 151.

but this he corrects when visiting the river later (March 11, 1841) [1] to 130 metres wide, 3 fathoms deep, the depth on the voyage up (Dec. 1840) being 4 fathoms; this would give the December discharge as about 700 cubic metres per second.

The next measurement was made by Knoblecher[2] December 2, 1849 who found the river at 5 kilometres above the junction to be 100 metres wide with a mean depth of 6 metres and a mean velocity of 0·333 metre per second which corresponds to a volume of 200 cubic metres per second discharged, a very low value for this season.

In 1862 Pruyssenaere [3] visited the Sobat and ascended it as far as the village of Petherick's interpreter (lat. 9° 2′ 22″ N.) and measured a discharge of the river on June 15 with the following result:—

Width 317 metres, depth 8 metres in centre 4 metres at 10 metres from the banks while the velocity was rather over 2 kilometres per hour or 0·56 metre per second; from this is deduced a section of 1939 square metres and a discharge of 1066 cubic metres per second. The point of measurement is about 160 kilometres from the junction with the White Nile. At this time the river was already rising rapidly since he records a rise of 4 feet between the 9th and 16th of June.

In April 1862 Petherick [4] measured the discharge but no details are given, it was doubtless near the mouth of the river and the result was 120 cubic metres per second.

On June 6 of the following year 1863 Petherick [5] again measured the discharge with the following result :

Total width = 309 feet 3 inches = 94 metres.
Velocity 16 feet 3 inches in 14 seconds = 0·358 metre per second.

The depths on the section were :—

Metres	2·6	5·1	8·7	10·8	12·1	10·2	9·0	7·7	4·8

giving a discharge of 233 cubic metres per second at a point described as half a mile above the junction with the White Nile.

De Malzac's paper quoted by Lejean show that he measured a discharge opposite the Sobat fort on April 4; the year is not stated but it was probably 1859.[6]

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[1] Ibid vol. II, p. 234.
[2] Jahrb k. k. "Central Anstalt Meteor. u. Erdmag. Bd." VII, p. 530.
[3] Pet. Mitt. Ergänzungsband. XI. 1877.
[4] Jour. R. Geog. Soc. 1865, p. 289.
[5] Proc. R. Geog. Soc. VIII.
[6] Bull. Soc. Geog.. June 1862.

The total width was 68·3 metres and the velocity was 17·84 metres per min. or 0·298 metre per second.

The measurements in metres were as under:—

Distance from right bank	3	10	17	24	31	38	45	52	54	65
Depth	1·4	2·2	4·2	5·7	5·6	5·3	4·6	4·5	3·2	2·1

The result gives 80 cube metres per second as the volume discharged.

In 1874 Lieut. C. M. Watson R. E. was at the mouth of the Sobat on the 25th October 1874.[1] The width was found, by triangulation, to be 134 metres; the velocity as the average of a number of trials 1·85 kilometres per hour or 0·953 metre per second while the river is described as quite full. If to this width we join the depths obtained in recent measurements the discharge would be about 910 cubic metres per second.

During the past 5 years more careful measurements have been made at low stage and at flood, which are given in the following table, but no accurate values are yet available for November just before the fall commences and these would be of interest. Besides Watson's observation above, that of Lieut. Julian Baker already quoted,[2] shows that the effect of the Sobat flood up to December is very great.

Sobat River.

Distance from mouth	Date	Width	Mean depth	Area of section	Mean velocity	Discharge
km.		m.	m.	m^2	m.p.s.	m^3.p.s.
45	April 6, 1901 ..	97	4·12	401	not measured	87 [3]
40	„ 17, 1903 ..	123	3·36	414	0·124	45
25	August 28, 1902 ..	97	7·64	729	0·794	572
25	Sept. 23, 1902 ..	140	7·12	928	0·830	771
25	August 26, 1903 ..	124	8·24	948	0·820	769
25	Sept. 26, 1903 ..	120	9·54	1030	0·868	895

It has been frequently stated that the water of the Sobat in flood is of a milky white colour and that this gives the name of the White Nile to the main stream into which it flows, but more accurately the colour of the flood water is a light brick-red when the river is rising to its maximum but by November it has cleared to a milky white as all the heavier particles have been deposited. By the time the water reaches Doleib

[1] MS. Notes kindly communicated by Col. Sir C. Watson.

[2] p. 120.

[3] Obtained by difference between volumes discharged by White Nile above and below Sobat mouth.

Hilla after its course of 500 kilometres through the alluvial plain it contains very little mineral matter in suspension, as is shown by the following analysis[1] of a sample taken in September 1903 about 25 kilometres from the mouth :—

	Parts par million
In suspension:—	
Organic matter	traces
Mineral	18·6
In solution:—	
Lime	12·8
Magnesia	5·3
Soda / Potash	Not determined
Ammonia from organic matter	0·25
Carbonic acid	Not determined
Sulphuric „	trace
Nitric „	„
Phosphoric „	Not determined

This low amount of suspended matter explains the comparative freedom of the White Nile from sand banks in spite of its low velocity and the large volume of water which it receives from the Sobat in flood. The island immediately opposite the Sobat mouth may be due to the deposited material brought down by this river but also it may be due to the ponded up waters of the White Nile having gradually cut a channel behind the present island thus facilitating the drainage of the flooded area up-stream.

Summary.—In the Sobat river then we have a comparatively short mountain tract, probably not much exceeding 200 kilometres in length from its source to Gambela, in which the stream descends about 1200 to 1400 metres; beyond this is a length of 540 kilometres in which the rapid flushes of the upper river die out, producing a regular rise and fall. This association of mountain and plain tracts, with but a short intervening region of valley tract where the slope is moderate, results first in a large deposition of suspended material immediately on reaching the plains, and also in an extensive flooding of the level country, which partly is evaporated and partly maintains the level of the Sobat in October and November when the rains on the tableland have greatly diminished.

The share of the Sobat in the regimen of the Nile is an important

[1] By Mr. A. Lucas in the Survey Department Laboratory.

one; in April the 400 cubic metres per second furnished by the White Nile upstream of it is increased by its early rise as soon as the rains reach the Abyssinian hills, while its flood water ponded up in the White Nile valley during the Blue Nile flood, increases appreciably the supply in December and January. Finally the Sobat together with the Blue Nile, as the two variable factors of the low stage supply, determines whether the summer supply (March to June) in Egypt is a good or bad one, a matter of no small importance in the present time of extended perennial irrigation.

CHAPTER V.

The White Nile or Bahr el Abyad.

The White Nile or Bahr el Abyad is usually considered to begin at lake No, where it is formed by the junction of the Bahr el Jebel and Bahr el Ghazal; flowing eastwards after 76 kilometres it receives the waters of the Bahr el Zaraf and 48 kilometres further it is joined by the Sobat on the right, which drains the south-western parts of the Abyssinian highlands. At this point the water furnished by the lake plateau and the basins of the Bahr el Ghazal, Bahr el Jebel and Sobat is collected, and no further addition is made to the White Nile except a trifling quantity by the Khor Adar, and the very moderate rainfall which does not exceed 900 mm. in the southern part of the basin and rapidly diminishes northwards; the evaporation from its surface is very large in the dry season, and even in the rains must be considerable.

Above the Sobat the White Nile basin is of small extent; a certain amount of plain on the left bank flooded in the rainy season, and partly drained by the Lolle, together with a small area on the right bank between the Bahr el Zaraf and the Sobat constitutes the whole of it. No extra supply of water is furnished by this part since it is mostly flooded by the White Nile when the Sobat is high as will be shown later (p. 167).

The area of the basin is about 353,500 square kilometres but the watersheds which bound it are not defined with any exactness; below its junction with the Sobat it includes a very large area of country on either bank; on the east its boundary inclines slightly north of east from the mouth of the Sobat to the hill masses of Beni Shangul and passing by Kirin runs fairly straight to Khartoum between the Blue and White Niles; on the west the limit lies a short distance beyond El Obeid, and goes from this point to opposite Taufikia on the south, and to Khartoum on the north, but the position of the watershed is everywhere ill-defined. The Khor Adar which comes in on the right bank a little downstream of Kodok is the only real tributary received by this reach of the river, but in the rains many small khors bring down for a few hours a certain volume of water but not enough to appreciably affect the main stream.

The Kordofan hills do not reach 1000 metres in altitude and probably only a few streams in the neighbourhood of Kirin on the west of the

Beni Shangul hills rise above this. The basin is then very shallow rising very gently towards its east and west limits, and being very slightly inclined to the north ; the White Nile lies nearly in the centre of it and by far the larger portion of the basin is less than 500 metres above sea-level.

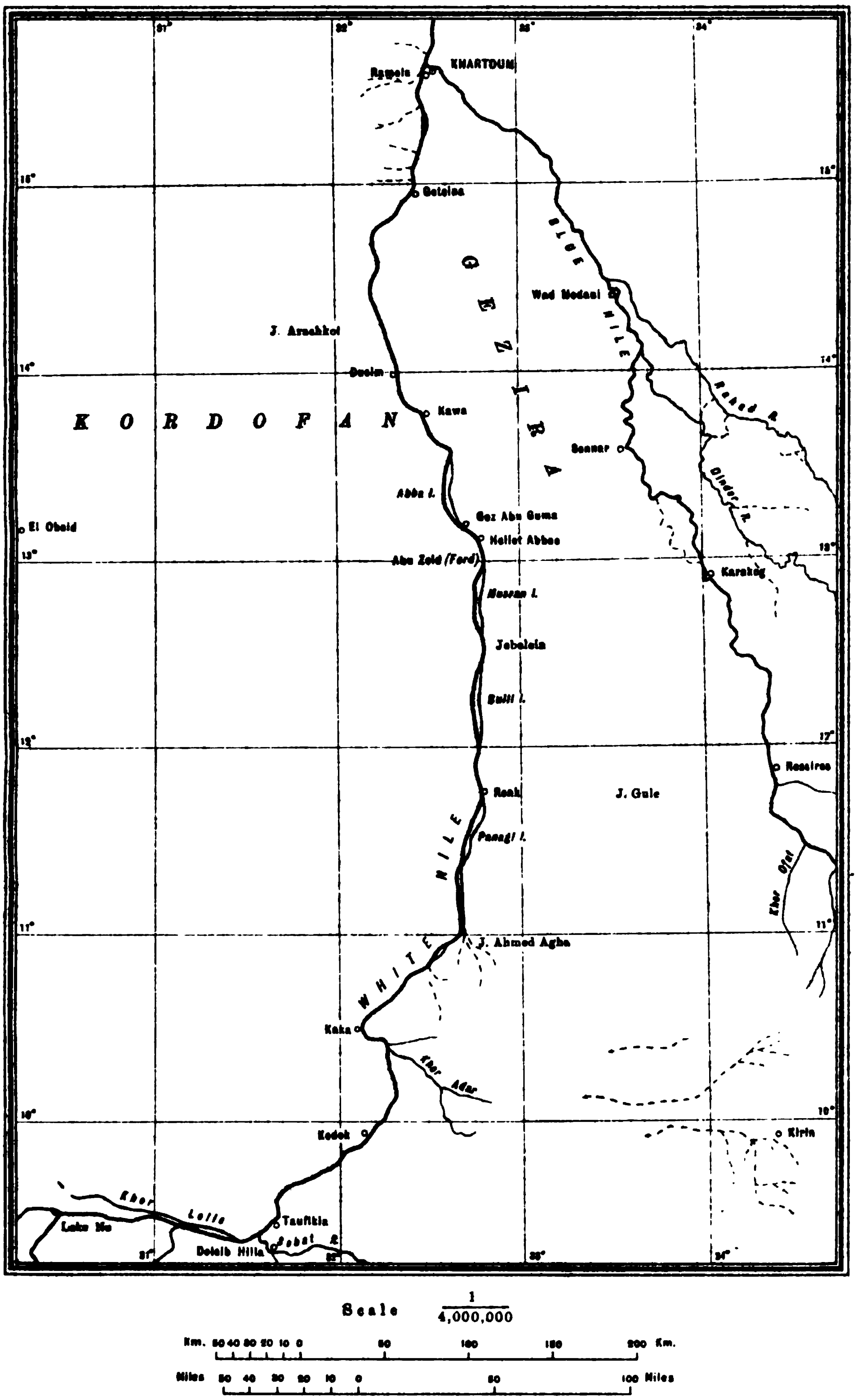
In the central portion a few isolated hills occur near the river ; the granite outliers of Jebelein and Arashkol and the volcanic mass of Jebel Ahmed Agha form well-known land marks, but as a rule the country is low and monotonous. All seems to point to this part of the country being a plain formed by the accumulation of material derived from the degradation of the Kordofan hills and those of the Gezira which must have been of much greater height in former times. Reduced now to rolling hills in an area of scanty rainfall, no active erosion is in progress and no streams flow to the Nile even in the rainy season, but all the rain that falls is speedily absorbed by the ground, and in the valleys such streams as may occur soon disappear beneath the surface. Thus the river flows through its alluvial deposits in a wide plain formed from the material furnished by the wearing down of the crystalline rocks on both east and west, where they still form isolated hills of granite and other allied rocks. Pruyssenaere[1] travelled along the eastern part of the basin in 1853 and recorded granite as forming the hill masses of Jebel Gule.

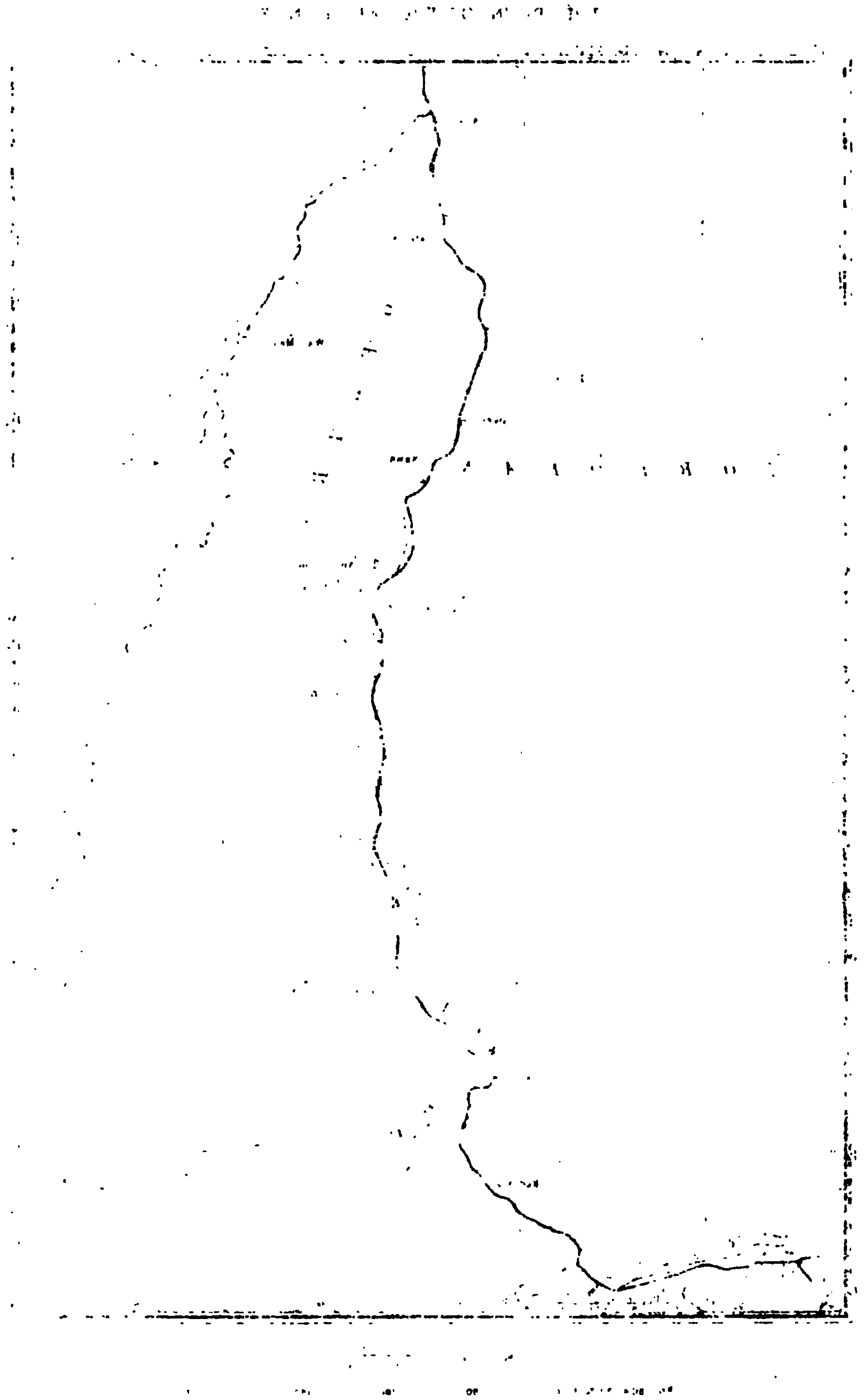
On the west a more detailed examination has been made by Dr. Linck.[2] He describes Kordofan as a plain lying from 600 to 800 metres above sea-level, and on this rise hills of moderate size to a further height of about 200 metres. Granite and quartzite are the predominant rocks, though at certain points gneiss and crystalline schists are extensively developed, and in some hilly regions, as in Tegele, phyllites and granular limestone occurs. Now a large part of the country is covered by a black soil more or less clayey, which in the dry season is intersected in every direction by shrinkage cracks. In the rains these rapidly close as the soil takes up water, while in the lower parts of many wadies swampy flooded tracts are formed which rarely drain to the Nile but dry by evaporation as soon as the north-east trade-winds recommence.

In past ages this region must have been a part of a mountain range which has gradually been worn down till only the stump remains. Even to-day weathering is proceeding rapidly in a climate where wide

[1] Pet Mitt. Ergänzungsheft 51, p. 5 ff.
[2] "Verh. d. Gesell, f. Erdkunde," Berlin 1901, p. 223 and N. Jahrb. f. Min. Geol. u. Pal. 1903.

THE BASIN OF THE WHITE NILE





and rapid changes of temperature take place for 8 months in the year, and many hills are now represented only by a confused pile of gigantic granite blocks, the remains of a single mass of rock which has been broken up by atmospheric agencies acting along the lines of jointing.

Climate. — The climate is well represented by Khartoum and Dueim in the north and by Doleib Hilla in the south supplemented by El Obeid in Kordofan; for eight months of the year, October to May, the climatic conditions of the Saharan type with clear skies, high temperatures, and very large diurnal range prevail, while being swept by the north-east trade-winds, the dryness is extreme. With the approach of the rainy season the wind becomes southerly, the humidity increases, and the temperature falls. The amount of rain varies considerably, diminishing rapidly from south to north, while on the steppes on either side precipitation is feeble, until the foot-hills of Beni Shangul are reached. Thus the addition to the volume of the Nile, even in the rainy season, may be considered as unimportant, and for the remainder of the year certainly the loss from its surface by evaporation is very great. This reach of the river is one therefore in which on the whole the supply of water is diminished rather than increased as it flows from Taufikia to Khartoum.

At the same time the White Nile plays an important part in the regimen of the river, for in the early summer when the springs of the Abyssinian tableland are nearly dry, and the summer rains have not begun, both the Blue Nile and the Sobat are at their lowest, and supply a very moderate amount (in bad years hardly measurable) to the Nile. Then it is the White Nile alone, fed by the Bahr el Jebel, with some assistance from the Bahr el Zaraf and the Bahr el Ghazal, which furnishes water to the Sudan and Egypt.

MEAN TEMPERATURE CENTIGRADE.

PLACE	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Years
Dueim[1] ..	20·7	21·4	26·0	30·2	**31·9**	31·1	28·3	28·4	28·1	29·2	26·2	22·4	27·0
El Obeid .	21·1	23·8	27·9	31·4	**32·1**	31·2	28·1	27·8	29·0	29·6	25·9	22·2	27·5
Khartoum	21·0	23·8	26·6	30·5	**33·2**	32·9	31·4	31·3	31·1	31·3	27·3	23·1	28·6

[1] Dueim observations from March 1902 to December 1904.
El Obeid " " July 1901 " " "
Khartoum " " " 1900 " " "

Mean daily maximum.

Place	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Dueim ..	33·2	34·1	37·7	**41·2**	40·8	40·1	37·3	36·5	38·9	40·9	37·4	34·1	37·7
El Obeid.	28·7	31·0	35·6	37·6	**38·7**	37·1	34·3	32·8	34·9	35·8	34·0	31·3	34·3
Khartoum	28·9	32·4	36·1	39·6	**42·0**	41·7	38·5	37·9	39·2	39·0	35·8	32·0	36·9

Mean daily minimum.

Place	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Dueim ..	11·6	12·2	17·3	21·6	24·6	**25·0**	23·5	23·1	22·6	22·5	19·2	13·7	19·7
El Obeid .	11·2	12·6	14·4	20·0	21·2	22·2	**22·7**	22·6	22·2	20·3	15·8	12·5	18·1
Khartoum	14·8	17·4	18·6	21·8	25·3	**25·8**	24·9	24·7	24·6	23·6	20·5	16·5	21·5

Range—maximum—minimum.

Place	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Dueim ..	20·1	21·2	**24·6**	21·2	15·3	14·2	13·8	13·2	15·4	18·2	18·6	20·6	17·8
El Obeid .	17·5	18·5	**20·8**	17·6	17·5	14·9	11·6	10·3	12·8	15·5	18·1	19·0	16·2
Khartoum	14·1	15·0	17·4	**17·8**	16·7	15·9	13·6	13·2	14·6	15·3	15·3	15·6	15·4

Mean extreme maximum.

Place	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Dueim ..	37·0	41·5	43·2	**45·5**	44·3	43·8	41·3	41·0	43·3	44·8	44·2	37·2	42·3
El Obeid .	34·7	42·6	**43·9**	42·0	41·3	39·6	38·7	38·4	37·6	38·7	37·6	35·4	39·2
Khartoum	36·0	39·2	39·6	44·4	44·4	**44·7**	42·3	41·5	42·6	41·8	39·9	35·9	41·0

Mean extreme minimum.

Place	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Dueim ..	6·0	5·5	11·8	15·5	20·0	**20·8**	19·8	19·3	18·8	18·2	13·9	7·8	14·8
El Obeid .	6·5	6·5	11·1	15·0	16·1	18·9	**19·0**	18·9	18·9	16·3	12·1	6·0	13·8
Khartoum	9·2	12·4	13·3	16·7	19·1	**21·4**	21·1	20·2	20·9	19·0	16·1	10·8	16·7

MEAN RELATIVE HUMIDITY, PER CENT.

PLACE	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Dueim ..	27	17	11	10	24	30	56	63	53	35	23	24	31
El Obeid.	28	20	16	21	31	40	62	71	62	40	30	26	37
Khartoum	28	26	17	15	22	31	43	48	40	32	29	31	31

VAPOUR TENSION IN MILLIMETRES.

PLACE	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Dueim ..	4·9	3·1	2·7	3·3	8·5	13·1	15·9	17·2	14·6	10·2	6·0	4·8	8·7
El Obeid.	4·1	3·0	3·2	4·1	10·0	11·3	15·5	17·7	14·4	9·6	6·1	4·6	8·6
Khartoum	5·4	5·4	4·6	5·1	8·2	11·0	13·0	14·6	13·0	9·8	7 4	6·6	8·7

El Obeid. LAT. 13° 10′ 34″ N. LONG. 30° 13′ 39″ E. ALT. 585 M.

DATE	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	YEAR
1902	..	..	..	..	..	..	92	105	70	55	0	0	[322]
1903	0	0	0	0	0	0	31	162	21	2	0	0	214
1904	0	0	17	0	2	9	149	67	53	6	0	0	303
1905	0	0	0	0	1	64	162	105	46	12	0	0	390
Mean..	0	0	6	0	1	24	108	110	48	18	0	0	315

El Dueim. LAT. 13° 59′ 31″ N. LONG. 32° 20′ 00″ E. ALT. 396 M.

DATE	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	YEAR
1902	..	..	0	0	36	0	127	69	60	6	0	0	298
1903	0	0	0	0	14	0	94	59	20	12	0	0	199
1904	0	0	0	0	0	9	53	46	53	0	2	0	163
1905	0	0	0	0	8	23	22	45	48	0	0	0	146
Mean..	0	0	0	0	14	8	74	55	45	4	1	0	201

Khartoum. Lat. 15° 36′ 20″ N. Long. 32° 32′ 30″ E. Alt. 378 m.

Date	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1899	0	0	0	0	0	1	13	12	?	6	0	0	[22]
1900	0	0	0	0	0	23	80	56	22	8	0	0	189
1901	0	0	0	0	0	16	7	3	0	8	0	0	34
1902	0	0	0	0	0	116	5	2	0	0	0	0	123
1903	0	0	0	0	24	0	18	12	14	0	0	0	68
1904	0	0	0	0	0	0	34	76	20	0	0	0	130
1905	0	0	0	0	6	16	8	75	4	50	0	0	159
Mean..	0	0	0	0	4	25	24	34	10	10	0	0	107

Mean rainfall in millimetres.

Place	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Dueim ..	0	0	0	0	14	8	74	55	45	4	1	0	201
El Obeid.	0	0	6	0	1	24	108	110	48	18	0	0	315
Khartoum	0	0	0	0	4	25	24	34	10	10	0	0	107

Percentage of mean wind direction at Dueim. (Mar. 1902-Dec. 1904).

Months	N	NE	E	SE	S	SW	W	NW	Calm	Mean direction
January ..	54	1	0	0	0	0	0	45	0	N 16½° W
February ..	53	2	0	0	0	0	0	45	0	N 15° W
March.. ..	66	1	0	1	0	2	7	23	0	N 14° W
April	45	11	6	4	6	3	4	20	1	N 2° W
May	18	3	8	9	25	10	9	14	4	S 45° W
June	3	2	5	7	44	9	8	16	6	S 15½° W
July	1	0	2	13	57	16	5	6	0	S 6° W
August ..	3	2	1	13	58	13	7	2	1	S 6° W
September..	2	0	0	3	86	3	3	1	2	S 2° W
October ..	37	6	2	7	20	8	4	14	2	N 19° W
November..	59	6	0	0	0	0	1	33	1	N 10° W
December..	57	4	0	0	0	0	0	39	0	N 13° W

Thus the White Nile basin is an area where high temperatures and dry winds prevail for about two thirds of the year, and the precipitation during the remaining four months is for the most part very moderate

in amount; consequently the tendency is for the available water supply to diminish rather than to increase.

Hydrography.—The regimen of the White Nile is of especial interest from the complicated conditions which it represents; the flood of the Sobat holds up the combined volumes of the Bahr el Ghazal, Bahr el Jebel and Bahr el Zaraf from August to November, and so floods the low-lying land, while the Blue Nile does the same on a larger scale at Khartoum in August and September. At the end of April the volume passing Taufikia is at its lowest since then the Sobat is discharging but little and the other rivers are almost constant in volume. At this time the first rains have usually fallen in southern Abyssinia, but no rise has taken place except in the small mountain tributaries. In May, however, the Sobat begins to rise and by the end of June the volume discharged may probably reach 800 or 900 cubic metres per second, when some 1200 cubic metres will be passing Taufikia. This amount increases steadily as the Sobat rises and is utilised in filling the vast shallow valley of the White Nile and the low-lying areas which border it, and through which the khors run. Further flooding, at all events of the lower reaches, takes place when the Blue Nile is in flood in August and September. In November the supply from the Sobat usually decreases, while the water which has filled the valley is rapidly being discharged at Khartoum, the maximum being reached as a rule in December, after which it quickly decreases as the Sobat falls at the rate of about one or two centimetres a day since the rains in Abyssinia are at an end.

From Lake No to its junction with the Sobat the White Nile flows across the general slope of the country in a shallow valley which has a very gentle inclination to the east; to the south is the basin of the Bahr el Jebel sloping northwards at about 1 in 13,000, while to the north there is an almost level plain for some kilometres, after which the country rises gradually to the hills of southern Kordofan. The slope of this part of the White Nile has recently been determined by levelling and in April 1904 was 1 in 38,500 between the mouths of the Bahr el Zaraf and the Sobat. Below this point for some 25 kilometres it was 1 in 34,500 and from about Goz Abu Goma to Khartoum it was about 1 in 100,000. Throughout the distance of 962 kilometres from lake No to Khartoum the White Nile flows as a wide stream of moderate depth and low velocity, which stores up in its valley a large amount of water to be run off as soon as the Blue Nile has fallen sufficiently. When by the end of February the Sobat has fallen considerably its function is a most important one as it supplies from the Bahr el Ghazal the Bahr el

Jebel and the Bahr el Zaraf a minimum supply of water which is increased more or less by the Sobat and Blue Nile, but as these vary according to the rains of the previous autumn it is the constant supply brought down from the southern tributaries which is of primary importance.

Lake No or Mokren el Bohur, is a very moderate sized shallow sheet of water, roughly four kilometres by eight and not as a rule more than 2 or 3 metres deep. In the rainy season when the water level of this part is raised by the rise of the Sobat in flood, it is enlarged by the flooding of the low-lying land on its shores, but this flooding is not nearly so great as has been assumed in describing the whole swamp area as flooded 3 metres deep. In September 1903 the water on the north shore of lake No was about 75 centimetres deep due to the rise of the Sobat in flood, and between that date and the middle of December when the Sobat reached its maximum the river rose about 60 centimetres more but its effect is probably to flood the valley of the Bahr el Ghazal where Dyé noted the maximum rise as 22 centimetres in December. At low stage the water slope from the Bahr el Zarnf to the mouth of the Sobat is 1 in 38,500; with a rise of 3 metres in the Sobat and 1 metre at lake No the water-slope becomes 1 in 103,000. Whether the extra rise which took place before December further decreased the slope or whether as at Dueim the level at both places rise and fall equally when once the critical slope has been reached, the data at present available do not decide. The slope of the water surface from Ghaba Shambe to Lake No is estimated to be about 1 in 19,000 so, that even if there was flooding to a depth of 2 metres at lake No it would disappear at a very moderate distance up-stream and would not entail the flooding of the whole swamp area to a depth of 3 metres, as has been maintained.

It has been said more than once that the channel of the Bahr el Jebel and of the White Nile between lake No and the Bahr el Zarnf diminished greatly in width between 1841 and 1880[1]. As there is no evidence which will allow us to say that the rainfall in this area and in the districts to the south of it was markedly less towards the end of this period, it follows that if the statement be true, the marshes have in these later years been receiving a larger proportion of the river supply than formerly.

Selim Kapitan on December 18, 1839 measured the White Nile just below lake No and gives[2] the width as 100 paces, the depth 3½ "Kouladjis"[3] and the velocity 1½ miles per hour.

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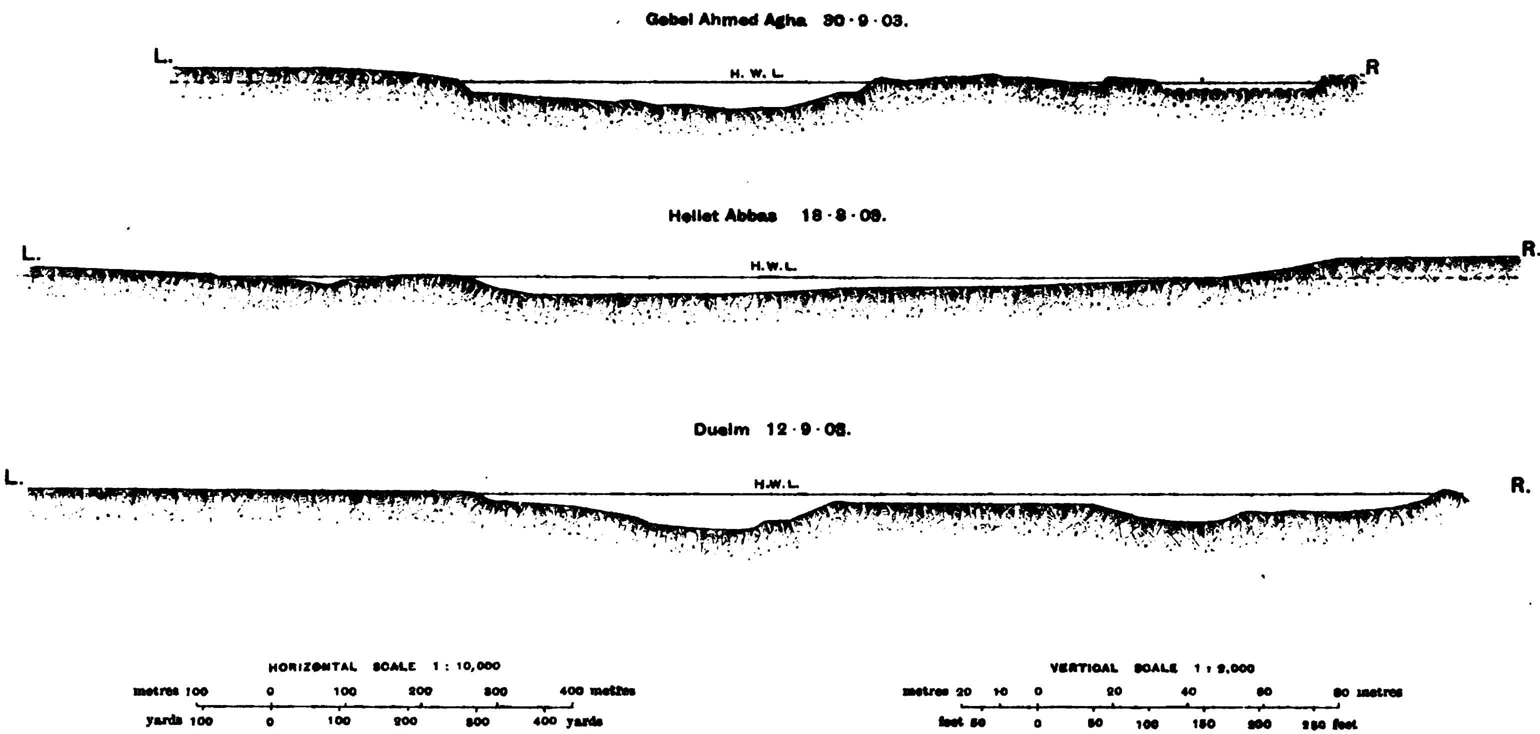
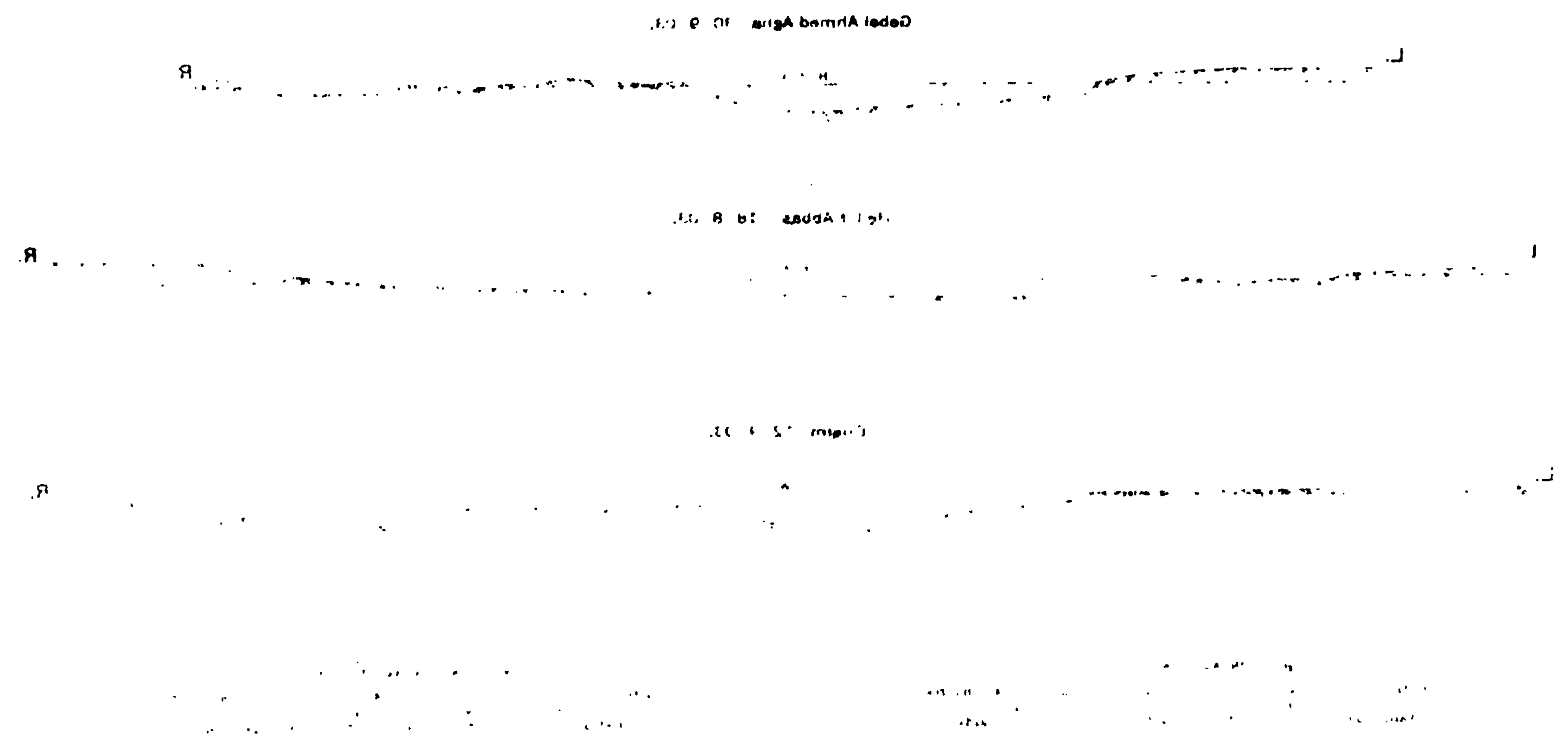
[1] The Nile in 1904, p. 46.
[2] Bull. Soc. Geog. Paris 1842 t. XVIII., p. 28.
[3] Fathoms.

SECTIONS OF THE WHITE NILE VALLEY



SURVEY DEPT.

SECTIONS OF THE WHITE NILE VALLEY



Werne[1] in March 1841 describes the shores of lake No as from a few inches to half a foot high and dry. Lake No had falled about a foot since November; it was a lake but of moderate size.

Poncet[2] says that the White Nile below the mouth of the Bahr el Jebel in summer (probably about 1858-59) was 70 metres wide 7·20 metres deep and flowing with a mean velocity of 0·40 metre per second, which would give a discharge of about 200 cubic metres per second; on August 15 in the height of the rainy season he considered the volume to have increased by one-third, the velocity being double while the water had topped the banks since the beginning of July, and did not return to the channel till the end of October and in some years until December.

That reaches of the White Nile down-stream of lake No should flow in curves amid masses of green reeds, etc., while beyond these the higher ground with its dry brown reeds and grass forms straight lines of bank, is not evidence of a river which has shrunk into a part of its bed. The river is meandering in its present flood plain which, as its load of silt has been deposited in marshes and lagoons before it has reached this point, is no longer being raised by deposit and is at water-level or very little above it so that reeds and grass grow green and luxuriant. The yellow line of the higher ground is an older alluvial deposit which forms the margin of the shallow valley within which the river now meanders.

North of its junction with the Sobat the White Nile is at first from 300 to 400 metres wide flowing between shelving banks on which are numerous villages and groves of the dom and deleb palms. Small islands a kilometre or two in length are fairly frequent between Taufikia and Kodok but they nowhere reach the size of those further north. Khors running more or less parallel to the river are not infrequent and are usually from 15 to 20 kilometres long. The direction is generally northerly with here and there bends to the north-east or north-west until Khartoum is reached, and this direction is followed by many of the drainage lines in the country to the east, where they only turn westwards as they near the White Nile.

In the reach from Kodok to Jebel Ahmed Agha the parallel khors or water channels attain a considerable development on the right bank while the river channel has become markedly wider; islands are fairly numerous and near Jebel Ahmed Agha there are several large ones.

[1] The White Nile, London 1849, vol. II, p. 118.

[2] Le "Fleuve blanc," p. 46.

From Jebel Ahmed Agha to Dueim, a distance of 370 kilometres, these islands and khors reach their greatest length and form a marked feature of this reach of the river; Panagi island near Renk (lat. 11° 45′ N.) is 40 kilometres long and 4 broad, Bulli and Musran islands are of the same length but rather narrower, while Abba Island is somewhat longer. From Dueim (lat. 14° N.) to Khartoum the river is of a different character; about a kilometre or even more in width it is practically free from islands, the khors exist on the left bank only where they intersect a cultivated tract which is in marked contrast to the right bank where cultivation extends but a short way inland, and beyond this distance is dependent on the water derived from wells and from the summer rainfall.

Thus the White Nile may be conveniently divided into four reaches each distinguished by special features:

1) Lake No to the Sobat river in which low marshy areas occupy the banks which are flooded in the late summer and autumn by the rise of the Sobat.

2) The Sobat river to Ahmed Agha in which islands are small, khors parallel to the main stream are of considerable length and on the left bank as far as Kodok after which they are on the right bank.

3) Ahmed Agha to Dueim in which the islands reach a great size, long khors lie on the right of the main stream, only one, khor Nagor, a short distance north of Jebel Ahmed Agha, being on the left.

4) Dueim to Khartoum in which there are no islands, khors are on the left bank only where most of the cultivation lies.

These khors which run parallel to the river and usually at a short distance from it are typical of this part of the Nile; usually 100 to 200 metres wide they are often 2 metres and more in depth, and frequently contain water of varying depth throughout the year in the northern portions; the southern portions near the river are shallower. Though their dimensions are now so small they show every sign of having been former branches of the river and often in all probability mark the approximate position of what was once the main channel but which now has dwindled to small dimensions by silting up and the growth of vegetation.

The White Nile has been put forward by Schweinfurth [1] as a typical case of Baer's law, viz: that in consequence of the rotation of the earth a river in the northern hemisphere erodes its right bank more than its left from the current setting more strongly against it. He

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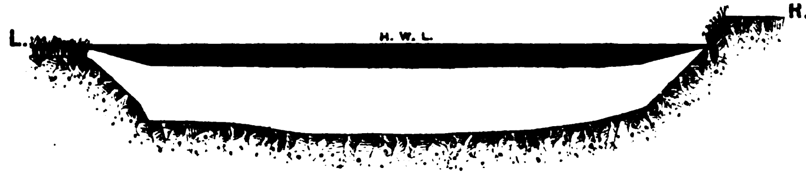
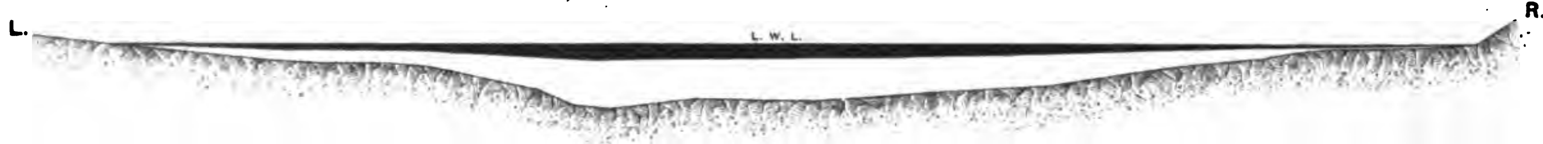
[1] The Heart of Africa. London, 1873. Vol. I, p. 54.

SECTIONS OF THE WHITE NILE

No. 1 7 Km. below Zaraf junction 30·8·02.

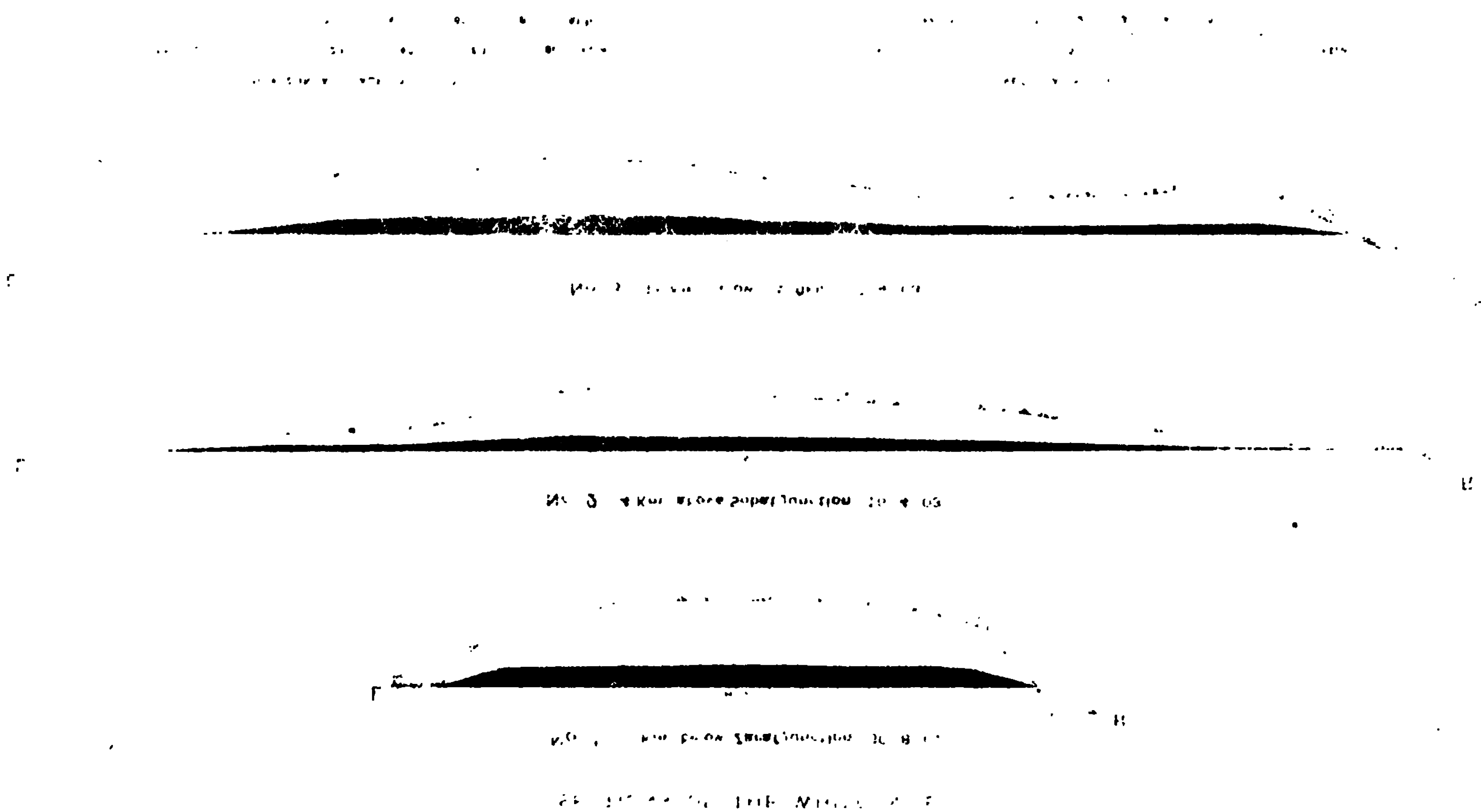


No. 2 4 Km. above Sobat junction 16·4·03.



No. 3 14 Km. below Taufikia 17·4·03.

SURVEY DEPT.



considered that the right bank of the White Nile was the steeper and the left the more gently sloping of the two. This may be the case at some points though not universally throughout its length, but it is very improbable that the earth's rotation is the sole cause in this instance. At Taufikia the velocity of rotation of a particle on the earth's surface as compared with that at Khartoum is proportional to the sines of the latitudes[1] or as sin 9° 30′: sin 15° 56′, or as 1 : 1·63; but the velocity of the water at Taufikia varies from about 0·350 metre per second in April to about 0·660 metre per second in September and perhaps even a higher value in November when the Sobat begins to fall, while at Dueim the velocity is never higher than 0·550 metre per second and falls as low as 0·120 metre in flood (see p. 173). The NNW. wind which blows strongly during the greater part of the year is probably a much more important factor in producing any modification of the right bank.

Schweinfurth's observation was made at Geteina, between Dueim and Khartoum and here as we have seen above the river is certainly pressing on its right bank, but further to the south from Jebel Ahmed Agha to Dueim where the large islands lie to the right of the main stream and khors indicating probably former positions of the river bed lie on the same side, it seems more than probable that here the river is inclined to erode its left bank. In November and December when northerly and north-westerly winds are blowing the largest discharge is passing Dueim, and the combined effect of these two factors is to erode the right bank. What the cause may be which inclines the upper portion to erode the left bank is unknown but the fact seems indisputable. In any case these khors are but channels of the White Nile and its branches which are being gradually effaced, and do not in any way represent the limits of the bed of a stream which once carried the Blue Nile water southwards into the region now occupied by the Bahr el Jebel, and within which bed the present White Nile channel is now situated.[2] This assumption that the Blue Nile ever flowed southwards is unsupported by any evidence such as the existence of thick alluvial deposits near Taufikia, where it is said to have emptied itself into a lake, or any proof of such a complete reversal of the drainage of some 700 kilometres of country without interfering with the course of the Blue Nile above Khartoum, while the absence of all signs of a vast lake directly contradicts the hypo-

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[1] The accelerating force of the earth's rotation is given by $2V\omega\sin\varphi$ where V is the velocity of the water, ω the angular velocity of the earth and φ the latitude of the place.

[2] The Nile in 1904, p. 41.

thesis. It is the assumption that the marshy plains of the Bahr el Jebel and Bahr el Ghazal represent a former lake basin that necessitated this hypothetical diversion of the Blue Nile.

A series of discharges measured in the southern portion of the White Nile in recent years are given in the following table which shows that the volume passing down varies between 350 and 450 cubic metres per second except for the supply furnished by the Sobat in flood. It has been suggested that the discharging capacity of the White Nile below the Sobat is the controlling factor of the flooding above this point but this view is untenable. The gauges at Doleib Hilla on the Sobat and at Taufikia on the White Nile below the junction rise in accordance and it is not until the Sobat has begun to fall that the Taufikia gauge decreases more slowly than the other since the water held up by the Sobat flood can now flow away. The White Nile valley is wide and open with shelving banks and there is nothing of the nature of a constriction which could hold back the water.

DISCHARGES OF THE WHITE NILE[1].

PLACE	DATE	Width	Mean depth	Section-al area	Mean velocity	Dis-charge
		m.	m.	m².	m.p.s.	m³.p.s.
7 km. below Bahr el Zaraf	Aug. 30, 1902	167*	4·88	813	0·414	336
6·5 „ „ „	Sept. 22, 1902	270*	3·90	1054	0·398	419
21 „ above Lolle	Sept. 22, 1903	180*	6·24	1034	0·435	450
0·5 „ below Lolle	April 16, 1903	365*	2·03	710	0·492	349
24 „ „ Sobat	April 6, 1901	286	3·87	1081	0·284	381
14 „ „ Taufikia ..	April 17, 1903	327	3·30	1068	0·345	368
14 „ „ „ ..	Aug. 26, 1903	404*	5·65	2174	0·540	1046
13 „ „ „ ..	Sept. 26, 1903	347*	6·67	2332	0·558	1304
13 „ „ „ .	Sept. 25, 1902	{306 158}	5·82	1983	0·656	1272

* Much of the section was very shallow.

The White Nile is intimately connected with the phenomenon known as the green water.

The season of lowest Nile is marked by the unusual greenness of the water, which has a marshy and putrid taste and smell, which boiling or distilling only increases. The green colour is due to large quantities of microscopic algæ [2] which are floating in the water, and it is the oil contained in some of these which gives the unpleasant taste and smell. Since d'Arnaud, after his visit to the Bahr el Jebel in 1841, attributed this algæ-laden water to the rising flood of that river

[1] Report on the Upper Nile App. IV and Plate VIII o, p. q.
[2] Kaufmann, "Revue de l'Egypte," p. 105. Cairo, 1897.

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which forced out of the lagoons and marshes the stagnant water which had been lying there, later writers have accepted his explanation of this "green water." It is not, however, a satisfactory one. The earliest rise of any magnitude in the Bahr el Jebel at Gondokoro, lat. 4° 55′ N., does not take place until June, while the green water is usually seen about Dueim, lat. 14° N., in the middle of May. Observations in particular years give the same result, and in 1902 the green water was filling the White Nile at Dueim and northwards nearly as far as Khartoum on May 11, on which date the Bahr el Jebel at Gondokoro rose markedly for the first time that year.

The green water at Dueim in May cannot, therefore, be that which has been forced out of the marshes of the Bahr el Jebel by the rising flood. I have suggested [1] that it may be brought down the Sobat from the Pibor marshes, as the first rise of the Baro takes place in the beginning of May; but in 1903 the first rise of the river at Doleib Hilla (12 kilometres from the junction of the Sobat with the White Nile) was marked by muddy and not by green water, and in 1902 no green colour was noticed. It seems therefore that while these minute algæ are brought down throughout the year by the water from the marshes of the Bahr el Jebel and the Bahr el Ghazal, they do not multiply rapidly in the White Nile until conditions of hot sun and low velocity of current appear, such as occur in May. Dr. Schweinfurth has suggested that this growth of algæ may take place in the pools and backwaters of the different cataracts ; as the conditions there must be entirely favourable, it is probable that is does do so, but only to a small extent, since the area would be but small; in any case, it has not been actually observed there. Mr. T. Barron noticed in August, 1903, this same green coloration of the water at Dueim, when the White Nile water was being held up by the Blue Nile flood, and the current in the White Nile was hardly appreciable. This confirms the view that these algæ grow in the White Nile reach when conditions are favourable, and are not brought down from the marshes of the Pibor, since the Sobat is in August discharging 800 to 900 cubic metres per second of reddish muddy water. On reaching Egypt in June, this green water occupies a considerable length of the river—500 kilometres, according to Kaufmann, who made observations on this point in 1896. As in May the White Nile is furnishing practically the whole supply of the Nile, this green water fills the river, and becomes greener as the algæ multiply. After June the rising flood of

[1] Blue book, Egypt No. 1, 1903. p. 70.

the Blue Nile is on its way down the river, and, flowing with greater velocity than the green water, overtakes it, carrying it down before it, and thus produces the phenomenon of the sudden change from the green water to the muddy red-brown flood.

The volume discharged by the White Nile was measured in 1902 and 1903[1] with the following results :—

WHITE NILE, DUEIM.

DATE	Mean depth			Sectional area			Mean velocity in metres per second			Discharge in cubic metres per second				Gauge in metres
	E	I	W	E	I	W	E	I	W	E	I	W	Total	
	m.	m.	m.	m²	m²	m²								
1902														
May 13	1·5	..	3·2	408	..	904	0·198	..	0·255	87	..	260	347	0·51
June 11	1·6	..	3·1	625	..	1038	0·314	..	0·426	205	..	445	650	1·00
July 8	2·2	..	3·5	842	..	1261	0·314	..	0·396	277	..	511	788	1·44
Aug. 5	2·8	..	3·9	1217	..	1562	0·311	..	0·284	385	..	482	867	2·20
Sept. 2	4·1	1·4	4·7	2100	372	1990	0·061	..	0·165	37	..	293	330	3·48
Oct. 1	3·3	1·6	4·8	1858	490	1878	0·196	..	0·276	360	..	510	870	3·50
„ 28	2·0	1·5	3·8	1319	500	1753	0·268	..	0·266	365	..	437	802	2·50
Dec. 1	2·5	..	3·5	1218	..	1480	0·306	..	0·337	392	..	538	930	2·05
„ 29	2·7	..	3·4	1198	..	1425	0·506	..	0·567	623	..	895	1518	2·02
1903														
Jan. 27	2·2	..	3·1	763	..	1138	0·257	..	0·347	213	..	450	663	1·12
Feb. 24	1·7	..	3·0	420	..	1020	0·187	..	0·300	127	..	335	462	0·46
Mar. 24	1·4	..	2·6	401	..	837	0·277	..	0·452	137	..	422	559	0·86
April 21	1·3	..	2·8	406	..	786	0·243	..	0·416	109	..	306	415	0·36
May 19	1·2	..	2·7	386	..	827	0·297	..	0·373	122	..	325	447	0·38
June 16	1·8	..	2·9	708	..	1092	0·277	..	0·379	208	..	450	658	1·09
July 1	2·2	..	3·2	896	..	1304	0·335	..	0·416	311	..	573	884	1·31
„ 14	2·4	..	3·6	1018	..	1442	0·298	..	0·318	313	..	522	835	1·71
Aug. 4	3·5	0·3	3·9	1304	92	1694	0·217	..	0·264	304	10	454	768	62·4
„ 11	3·5	1·0	4·2	1698	285	1913	0·125	0·087	0·131	228	31	320	579	3·28
„ 18	3·8	1·3	4·7	1870	390	2152	0·136	0·143	0·097	254	62	218	534	3·68
„ 23	4·2	1·9	4·9	2171	573	2416	0·127	0·084	0·130	270	46	338	654	4·08
„ 28	4·3	1·9	4·9	2186	560	2490	0·125	0·113	0·142	269	62	379	710	4·19
Sept. 2	4·4	2·2	5·1	2162	625	2483	0·155	0·126	0·094	332	75	164	571	4·32
„ 7	4·5	2·3	5·1	2250	650	2500	0·158	0·108	0·119	357	62	318	737	4·44
„ 12	4·5	2·2	5·0	2250	649	2450	0·150	0·084	0·110	309	51	293	653	4·46
„ 18	4·5	2·0	5·1	2230	605	2475	0·183	0·090	0·142	397	53	390	840	4·23
„ 24	4·4	2·0	5·1	2240	595	2450	0·147	0·114	0·148	320	65	378	763	4·31
Oct. 7	4·4	2·0	5·0	2195	506	2493	0·308	0·225	0·255	700	110	778	1588	3·93
Nov. 3	3·4	0·8	4·1	1657	217	1980	0·400	0·163	0·404	680	35	848	1563	3·11
„ 24	3·1	0·3	4·0	1556	90	1816	0·450	..	0·457	773	..	892	1665	2·44
Dec. 8	2·6	0·2	3·7	1410	49	1724	0·419	..	0·427	629	..	833	1462	2·06
„ 22	2·8	0·1	3·4	1436	27	1676	0·411	..	0·415	620	..	783	1403	1·80
1904														
Jan. 6	2·7	0·1	3·8	1349	23	1770	0·427	..	0·460	601	..	907	1508	1·66
„ 20	2·8	0·1	3·7	1351	28	1666	0·438	..	0·487	603	..	863	1466	1·54

E = east channel; I = island, submerged in flood; W = west channel.

In these discharges the holding up of the White Nile water by that of the Blue Nile, when the latter is in flood, is very markedly shown, and the slackening of the current at this time of the year is a fact well known to the boatmen of the White Nile. It is this which leads to

[1] A Report on the Upper Nile, App. IV.

the extensive flooding which takes place above Khartoum, filling the khors and low-lying land along the river with water, which drains off when the Blue Nile flood has fallen sufficiently; this is usually in October. To further prove this, a series of measurements were made in the White Nile close to Khartoum, just above the junction with the Blue Nile, in order to see if there was a very feeble velocity there. Seven sets were taken during August and September, 1903, and the results are of considerable interest. [1]

On August 7, 1903, the measurements were made 1 kilometre above the ferry between Omdurman and Khartoum; one point was in the eastern half of the channel, the other in the western half.

EAST CHANNEL		WEST CHANNEL	
Depth from surface.	Velocity.	Depth from surface.	Velocity.
metres.	metres per second.	metres.	metres per second.
0	0	0	0
1	0	1	0
2	0	2	0
3	0	3	0
4	0	4	0

On August, 23, 1903, measurements were made at three points—the first, A, was in the centre of the White Nile channel close to the incoming water of the Blue Nile; the second was in the main channel 1 kilometre up stream; the third point was opposite the village of Ramela, 5 kilometres from the junction of the two Niles. At a short distance down-stream of A, the turbid waters of the Blue Nile could be seen carrying down with them masses of the clear White Nile water.

August 23.—

Depth from surface.	A.	B.	C.
metres.	metres per second.	metres per second.	metres per second.
0	0·276	0·243	0·264
1	0·172	0·150	0·198
2	0·195	0·083	0·099
3	0·218	0·034	0·075
4	0·230	0·048	0·039
5	0·195	0·018	0·023
6	0·264	..	0·057
7	0·184	..	0·078
8	..	..	0·034
Mean.. ..	0·217	0·096	0·096

[1] Geog. Jour. Sept. 1905.

After these preliminary experiments, the measurements were made on August 28, September 4, September 11, September 18, and September 24, off Ramela, at different distances from the right bank.

August 28.—

Depth from surface.	From right bank. I. 700 metres.	II. 1200 metres	III. 1400 metres.	IV. 1600 metres.
metres.	metres per second.	metres per second.	metres per second	metres per second
0	0·000	0·076	0·034	0.000
1	0·023	0·044	0·000	0·000
2	0·000	0·028	0·014	0·000
3	—	0·009	0·000	0·000
4	—	0·000	0·023	—
5	—	0·000	0·053	—
6	—	0·000	—	—
7	—	0·000	—	—
8	—	0·000	—	—
Mean... ...	0·008	0·017	0·021	0·000

September 4.—

Depth from surface.	From right bank. I. 700 metres.	II. 900 metres.	III. 1200 metres.	IV.
metres.	metres per second.	metres per second.	metres per second.	
0	0·391	0·299	0·345	
1	0·278	0·200	0·255	
2	0·306	0·242	0·283	
3	0·278	0·333	0·230	Too rough to continue; southerly gale.
4	0·290	0·200	0·188	
5	0·368	0·257	0·181	
6	—	0·271	0·191	
7	—	0·306	0·195	
8	—	—	0·131	
Mean... ...	0·318	0·264	0·222	

The effect of the wind in forcing down the White Nile water is here very marked.

September 11.—

Depth from surface.	From right bank. I. 800 metres.	II. 1100 metres.	III. 1600 metres.	IV. 2100 metres.
metres.	metres per second.	metres per second.	metres per second.	metres per second.
0	0·241	0·276	0·267	0·278
1	0·051	0 126	0·165	0·167
2	0·021	0·125	0·125	0·161
3	0·000	0·071	0·103	0·126
4	0·000	0·067	0·078	0·136
5	—	0·043	0·078	—
6	—	0·000	0·078	—
7	—	0·012	0·062	—
8	—	0·014	—	—
Mean... ...	0·063	0·082	0·120	0·174

September 18.—

Depth from surface.	From right bank.				
	I. 700 metres.	II. 950 metres.	III. 1250 metres.	IV. 1650 metres.	V. 1950 metres.
metres	metres per second.	metres per second.	metres per second.	metres per second.	metres per second.
0	0·276	0·315	0·292	0·260	0·202
1	0·115	0·108	0·124	0·120	0·085
2	0·039	0·044	0·087	0·085	0·037
3	—	0·030	0·067	0·071	0·000
4	—	0·016	0·057	0·057	—
5	—	0·000	0·051	0·032	—
6	—	—	0·028	0·009	—
7	—	—	0·025	—	—
8	—	—	0·000	—	—
Mean ...	0·143	0·086	0·081	0·091	0·081

September 25.—

Depth from surface.	From right bank				
	I. 600 metres.	II. 900 metres.	III. 1200 metres.	IV. 1750 metres.	V. 2250 metres.
metres.	metres per sec.	metres per sec.	metres per sec.	metres per sec.	metres per sec.
0	0·247	0·276	0·287	0·276	0·303
1	0·131	0·140	0·140	0·113	0·162
2	0·043	0·048	0·039	0·067	0·046
3	0·000	0·016	0·037	0·018	0·018
4	—	0·032	0·000	0·034	—
5	—	0·016	0·000	0·007	—
6	—	—	0·000	—	—
7	—	—	0·000	—	—
8	—	—	0·000	—	—
Mean	0·103	0·088	0·056	0·086	0·132

The mean velocity in the White Nile at Dueim and in the Blue Nile above Khartoum about the same dates were:—

Date.	White Nile at Dueim.	Date.	Blue Nile above Khartoum.
	metres per second.*		metres per second.
August 4	0·240	August 5	2·103
„ 23	0·114	„ 21	2·796
„ 28	0·127	„ 28	2·566 Maximum discharge
September 2	0·125	September 4	2·094 of Blue Nile.
„ 12	0·115	„ 11	1·960
„ 18	0·138	„ 18	1·814
„ 24	0·136	„ 25	1·879

* The mean of the mean velocities in the two channels and over the flooded island.

From these results the effect of the Blue Nile flood is plainly seen; the complete absence of current on August 4 was, doubtless, the result of the sudden arrival of the main flood of the Blue Nile about August 2 and 3, when the discharge rose from 2870 cubic metres per second on July 31 to 7584 cubic metres per second on August 5.

Throughout July and August, 1903, at Dueim on each occasion that a discharge was taken, the velocity was also measured at each successive metre from the surface at the deepest part of the section.

The water was found to be moving at all parts of the section until September 2, when there was a distinct reduction of the velocity near the bottom at several of the points at which the velocity was measured; this layer varied apparently from 1 to 2 metres in thickness. The same occurred on September 7, but to a less extent. On September 12 there was a layer of water a metre deep at the bottom which was not appreciably moving. This was found to be the case at five points—at 130, 175 and 265 metres from the east bank, and at 148 and 193 metres from the west bank. After this date the water was moving throughout the section.

It is now easy to see how Linant obtained his discharge of 6041 cubic metres per second for the White Nile in flood. He took his measurements on July 26, 1827, and therefore before the Blue Nile had reached its maximum; the surface velocity he obtained of 1.54 metre per second must have been taken very near the junction with the Blue Nile to have so high a value, since at Dueim 0·567 metre per second is the highest mean velocity recorded in 1902 and 1903 and since the volume discharged above the Sobat is nearly constant, there cannot be any marked increase of this mean velocity in any year; the velocity thus obtained applied to the whole or a greater part of the White Nile section will account for the high discharge obtained.

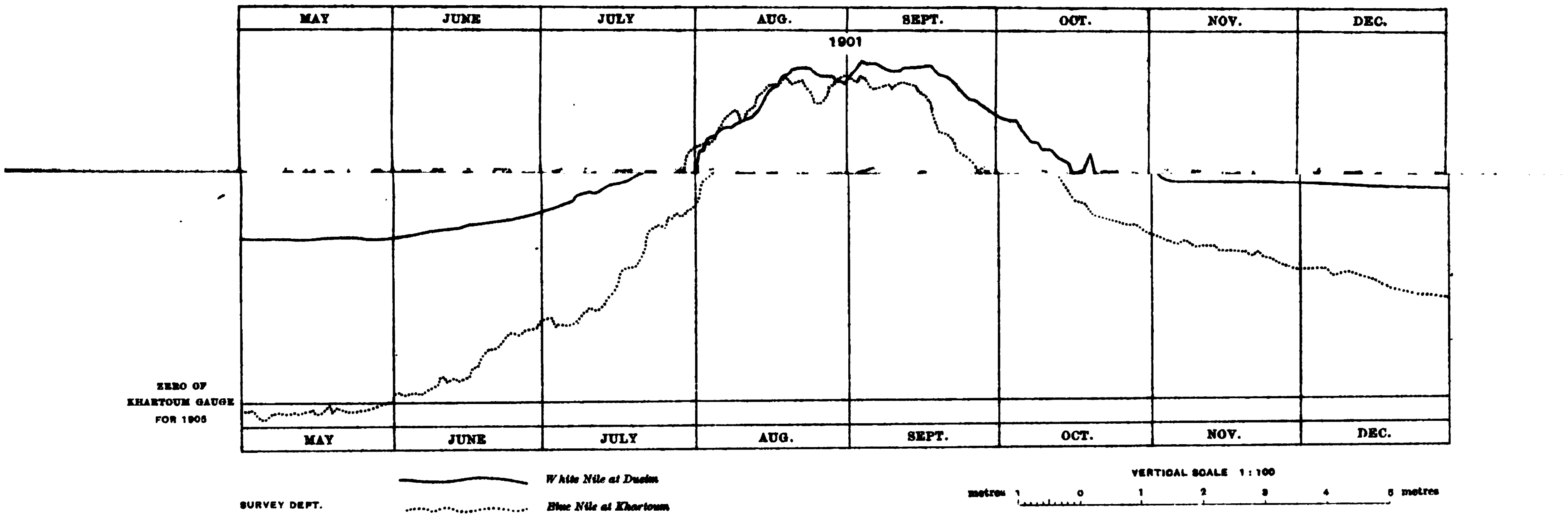
The earlier observations agree fairly well with those obtained in 1902 and 1903 at Khartoum and Dueim for the Blue Nile and for the White Nile at low stage, but the flood discharges of the White Nile show a very large discrepancy:—

1902.	Cubic metres per second.	1903.	Cubic metres per second.	Previous measurements.	Cubic metres per second.
July 8	827	July 14	835	July 5, 1848	3000
August 5	910	August 4	768	July 30, 1827	6044
Sept. 2	350	Sept. 2	571	Sept. 1876	4351

Thus it is evident that the surface velocities taken by former observers give a wholly false result, since the greater part of the White Nile is being held up by the flood of the Blue Nile and only a surface stratum

PLATE XX.

ACTION OF BLUE NILE IN FLOOD ON WHITE NILE



SURVEY DEPT.

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of the water near the junction was passing down with a velocity nearly the same as that of the Blue Nile water. It is very doubtful if at any time water flows from the Blue Nile *up* the White Nile channel, but throughout as has been stated to be the case July and August,[1] but this point is discussed in detail by Mr. J. I. Craig in Chapter VII. Seeing, too, that the Sobat flood-supply must be estimated at less than 1500 cubic metres per second, and that of the Bahr el Zaraf, Bahr el Jebel and Bahr el Ghazal combined at less than 500 cubic metres per second,[2] the maximum discharge cannot reach 2000 cubic metres per second under the present conditions, when the amount of flooding in the Taufikia-Khartoum reach, and the amount of water which the marshes lining its banks must absorb, is taken into account; also the discharges for 1902 and 1903 show that the maximum discharge of the White Nile takes place in December when the floods are subsiding, after the Blue Nile has fallen.

The manner in which the water of the white Nile is ponded back by the Blue Nile flood can be more satisfactority discussed after the Blue Nile basin and its regimen have been described.

Summary.—When we come to appraise the effect of the White Nile it amounts to the storing up of some 1500 million cubic metres of water in its valley from the Sobat flood, which is supplied to the Nile in October, November and December, thus modifying the fall of the water level in those months; for the next six months it furnishes the constant volume brought down by the Bahr el Jebel together with a gradually diminishing amount from the Sobat.

The Blue Nile drawing its low stage supply from the Abyssinian springs like the Sobat is also a variable factor so that the White Nile furnishes the irreducible minimum of the low stage to which are added varying amounts by the Sobat and Blue Nile. This additional supply depends upon the intensity of the summer and of the autumn rainfall on the table land; if one or other is good the low stage should be favourable, if both are bad as in 1899, 1902 1904 and 1905 considerable shortage of water in Egypt is the result in April-June of the following year. If both are heavy as in 1878 exceptionally high low stage level is maintained in the following spring (cf. Ch. X).

[1] Willcocks, "The Nile in 1904," p. 57. Cairo, 1905. See also Lyons, "The Rains of the Nile Basin in 1904." Cairo, 1905.

[2] Garstin, "A Report upon the Basin of the Upper Nile" p. 164. Cairo, 1904.

CHAPTER VI.

The Blue Nile, the Atbara and the Khor el Gash.

The Blue Nile.—Having now traced the White Nile from its most southern sources to Khartoum and studied its main tributaries as far as our present knowledge will admit, the same may be done for the group of rivers which flow westwards from the Abyssinian tableland, excepting the Sobat which has already been described. The most important of these are the Didessa and the Abai which with their tributaries form the Blue Nile, the Atbara, known as the Settit and Takkazze in its higher reaches, and the Gash or Mareb; each of these in their turn receive tributary streams of considerable size which will be alluded to later, but one and all are fed by the short heavy Abyssinian rainfall of May to September, and rising on the high tableland, pour down their deeply eroded valleys of high slope with great velocity carrying their load of silt which is in part deposited on the fertile plains of the Nile in Egypt.

The first stage will therefore be to describe the main geographical features of the Abyssinian tableland, its geology and its climate, since these affect similarly the different rivers, determining their drainage lines, their slopes, and the volume of water which flows to them.

Rising from the Sudan plains to an average altitude of about 2000 metres is the Abyssinian tableland, which extends from the shores of lake Rudolf on the south, to the north of Eritrea where it joins the ridge of hills which runs parallel to the western coast of the Red Sea; on the west it falls steeply to the western slopes of the Beni Shangul hills, and to the Sudan plains north of the Blue Nile, while its eastern escarpment, following closely the 40th meridian as a steep wall of rock and rising at many points to 2500 metres above the sea and sometimes even more, looks eastward over the low-lying plain some 300 kilometres wide which extends to the Red Sea. Mountain ranges and isolated peaks rise to greater heights on this tableland, especially the Simien Mountains (4620 metres) south of the Takkazze river and north of lake Tsana, the Chok plateau (4150 metres) between this lake and the Abai river, and the mountains (3000 metres) in which the Didessa, the Baro and the Birbir rise, the first-named flowing northwards to the Abai, while the other two flow westwards to the Sobat. It is

this high mountain region lying in the path of the East African monsun current which causes the moisture-laden air to rise, and consequently produces that heavy precipitation which feeds the Sobat, the Blue Nile and the Atbara and thereby provides the whole supply of the Nile, except some 450 cubic metres per second which is the joint contribution of the Bahr el Ghazal, the Bahr el Jebel and the Bahr el Zaraf (see p. 166). This tableland slopes gently westwards so that most of the rivers flow in this direction towards the Sudan plains through the deep gorges which they have eroded and follow the most devious courses before finally reaching the lower level. The Takkazze rising near the eastern escarpment flows at first west then north and then west again; the Abai flows northwards into lake Tsana, but almost at once leaves it in a south-easterly direction, then bending round to the west, finally leaves the hills in an almost northerly course to Famaka in the Sudan plains. Too little is yet known of these river valleys to say what has determined these abrupt changes of direction; in some cases more rapid development of a tributary stream may have led to its becoming the principal one and so diverting to itself drainage which formerly went to others, which may account for the present line of the Takkazze; in other cases earth movements may have produced lines of weakness along which erosion could proceed more rapidly and thus initiated a valley line such as has occurred at one place at least on the Abai (see p. 220), while the NW.-SE. and NE.-SW. directions of its reaches in the west of Abyssinia seem to agree closely with the principal lines of movement as given by Koettlitz.

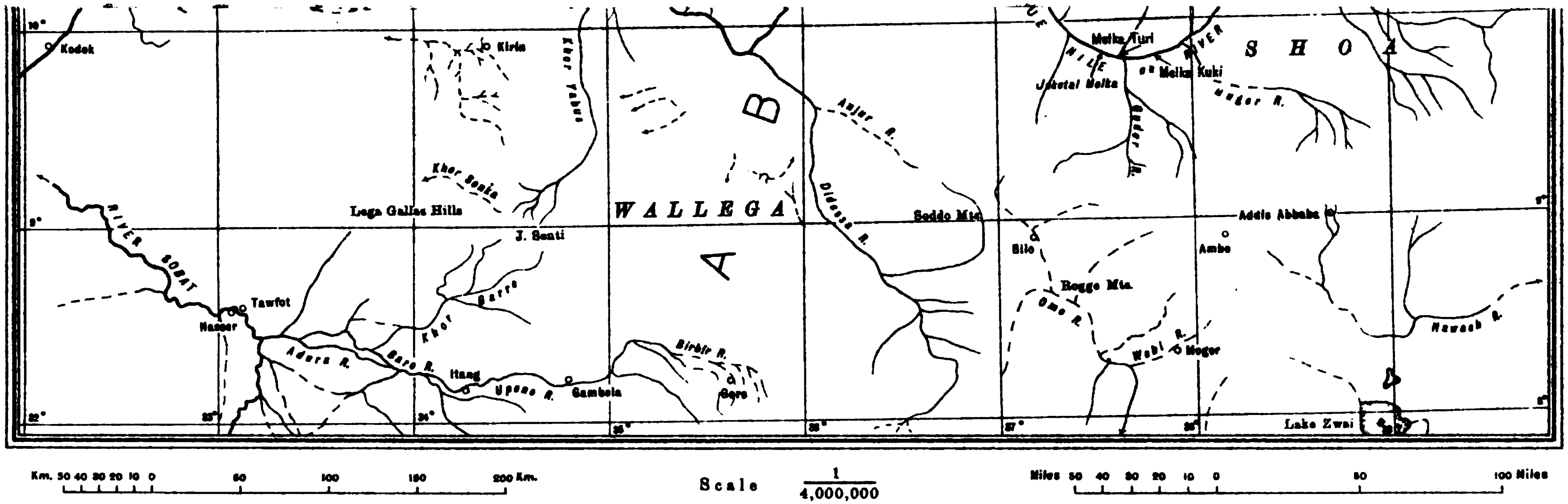
Thick sheets of basalt form the surface of the tableland over large areas and the vertical joints which divide it in all directions greatly facilitate the formation of the deep steep-sided ravines which are so marked a feature of the Abyssinian drainage systems. The rock itself weathers fairly readily to a rich soil which is carried down in vast quantities by the flooded rivers in the rainy season to be deposited in the lower reaches of the Nile. Aided by these conditions the larger rivers have excavated valleys 10 to 12 kilometres wide at the plateau level, and narrowing rapidly till at the bottom the river, 80 to 100 metres wide, flows with little more than a belt of forest on either side. The river is often as much as 300 to 500 metres below the plateau so that within a comparatively short distance lie the bare frost-bound peaks of the highest mountain rising to 4000 metres above the sea, the cool temperate climate of the plateau at 1800-2000 metres and the oppressive tropical forest of the deep

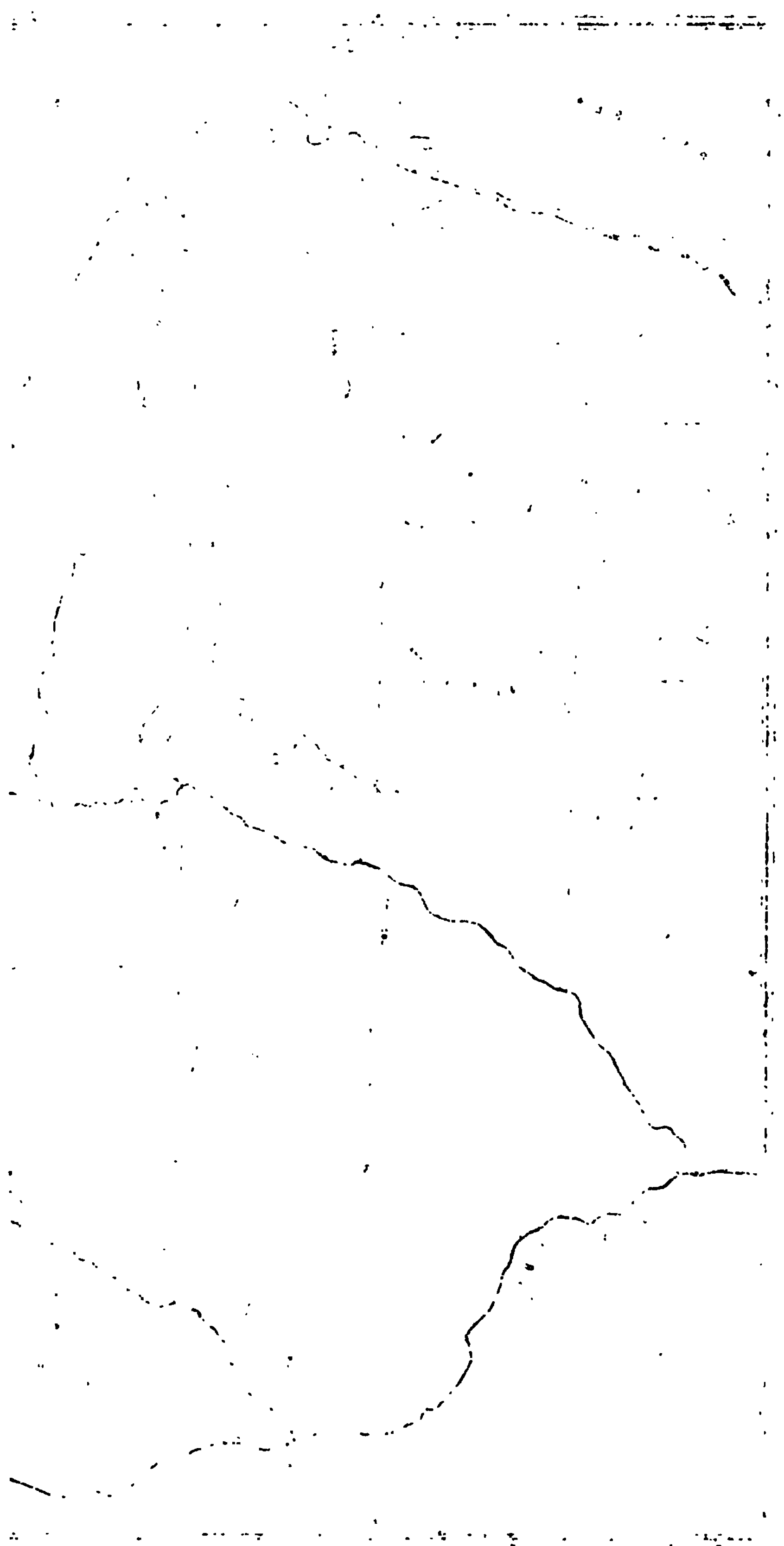
valleys which are avoided by the Abyssinians on account of their unhealthy character.

The area of the Blue Nile basin is approximately 331,500 square kilometres lying between the basins of the White Nile on the west, the Sobat and Omo on the south, the Hawash on the east and the Atbara and its upper portion the Takkazze on the north and east. Starting from Khartoum the limit of the basin follows the ridge between the Blue and White Niles as far as the Beni Shangul district; from here it turns southwards to Kirin and thence passing by the source of the Yabus turns south-east following an irregular course between the tributaries of the Baro and those of the Didessa river. It now turns north to latitude 9° N. and this approximately marks the watershed between the Nile and the Hawash as far as Addis Abbaba, beyond which the eastern escarpment of the Abyssinian tableland turns sharply to the north. From a point just north of Magdala on the crest of the escarpment, the watershed between the Blue Nile and the Takkazze starts westwards and skirting the north shore of lake Tsana runs between the river Dinder, and the Shinfa a tributary of the Atbara and thence to Khartoum. Of the whole of this area it may be said that up to long. 35° E. it is effective as a catchment basin, but west of this what rain falls adds but little to the supply of the river though it is of great importance to the agriculture of the district.

The geological structure of Abyssinia is known in its broader outlines though much has yet to be done to provide a complete description of this area. Its influence on the rivers which drain it can however be traced partially from our present knowledge. The tableland consists mainly of a mass of granite, gneiss, and schists on which have been laid down beds of sandstone above which in the eastern portion the limestone beds of Antalo occur. Subsequently to the formation of these an outpouring of volcanic rocks took place on a vast scale, which are divisible into two series, the lower or doleritic basalt and the upper or trachytic. Erosion has removed vast masses of these rocks and hill masses formed of them rise above the general level of the tableland as witnesses of their former extension, but even today the area they cover is a large one. In the northern portion, Eritrea, they are extensively developed in the neighbourhood of Halai, Chenafena, and near the source of the Mareb; east of the Takkazze from lat. 13° N. southwards they form the surface of the plateau and are exposed in the river channel to a considerable depth. The country round lake Tsana and to the east of it, as well as much of the province of Gojam south of the lake, is mainly covered by the same basalts and lavas, while south of the Blue

THE BASIN OF THE BLUE NILE,
THE ATBARA, AND THE KHOR EL GASH.





Nile similar rocks occur from the valley of the Hawash river on the east to that of the Didessa on the west. From here westwards granite and gneiss with diorite, diabase, and hornblende schist, occur, showing that we have reached the platform of the old crystalline series which appears in most of the large valleys such as the Abai, the Takkazze and the Mareb, in their middle and lower courses where they have cut down through the overlying volcanic series to the lower rocks, and it also seems that the western foot-hills of the tableland between the Blue Nile at Famaka and the Atbara at Gallabat (Metemma) are mostly comprised of these older crystalline rocks. The high tableland of south western Abyssinia drained by the Didessa and the Sobat is also formed of the volcanic rocks overlying the gneiss and granites which form the base of the plateau. [1]

From his study of the geology of the Abyssinian plateau between Addis Abbaba and the Nile at Roseires Dr. Koettliz [2] is of opinion that there have been two great periods of volcanic activity; the earlier when the basalt masses as well as lavas, tuffs and agglomerates were poured out through fissures and a later one when trachytes, rhyolites and andesites were discharged from volcanic vents, with their accompaniment of tuff. Probably in connection with these outbursts are the earth movements which have raised the rocks which form the Soddo mountains between the Guder and Didessa, south of the Abai; they have been tilted westwards and show steep escarpments facing east and south-east along the line of fault, having a general north and south direction. The Didessa is believed by him to follow another fault line and on the west of it the hills again rise in steep escarpments towards the east while their reverse slopes incline towards the Yabus as an undulating country. Here the basalt is of no great thickness and lies upon the schistose, granitoid and gneissic rocks which form the mass of the hills, and are much intersected by numerous quartz dykes.

The heavy rainfall of June to September falling on this elevated tableland of volcanic rocks, which are much intersected by vertical jointing, rapidly erodes stream courses in these strata, which deepen themselves until in many cases they reach the underlying crystalline rocks. The Bashilo near Magdala flows in a ravine about 1000 metres deep of which the steepness of the sides is broken by one or two ter-

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1 Neumann Geog. Jour. Oct. 1902, p. 396.
2 Geog. Jour. March 1900, p. 264.

races; the ravine of the Jitta river is 1050 metres deep with similar terraces, and the Takkazze flows in one about 600 metres deep at a point some 16 kilometres from its source.[1]

Similar terraces are reported to occur in the valley of the Abai but the description of them is not sufficiently clear to show whether they are due to different degrees of resistance in the beds which form the sides, or whether they represent periods when the Abyssinian tableland was stationary and rivers were able to widen their valleys, until a renewed rise enabled them to cut their channels rapidly deeper. The point is of considerable interest and worthy of investigation. The volcanic rocks weather comparatively easily and provide a reddish brown soil which is carried away in large quantities by the streams in the wet season and is borne by the waters of the Blue Nile and Atbara to Egypt where it is partly deposited on the flood plains of the river and partly carried down to the sea.

Climate.—Situated between the 6th and 16th parallels of north latitude the Abyssinian area has a typically tropical climate except for the strip of low-lying country on the east, between the plateau and the Red Sea, where there are regular winter rains. It belongs climatologically, as Woeikoff has said, to the region of the African monsun; over the greater part of the plateau October to April is an almost rainless period during which the prevalent winds are from the north and east; north and north-east winds prevail in the northern and western portion with north-east and east winds in the eastern and southern areas.

This dry season is followed by the rainy season, which is heralded by the short period of the lesser rains lasting about 3 weeks, and occurring in the latter part of March in Kaffa, and in March and April in Shoa, and Eritrea. At these places a distinct decrease in the rainfall occurs in May, while in June the rainy reason proper commences and reaches its maximum in July and August; in the middle of September the rain decreases abruptly and by the end of September it is practically over.

In the plains of the Sudan this annual alternation of dry and wet seasons occurs regularly over wide areas with little difference except that the amount of rainfall decreases steadily as the rain belt moves north.

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1 Markham, Jour. R. Geog. Soc. 1868, p. 41-44.

PLACE	Lat. N	Mean Annual rainfall mm.	Remarks.
	° ′		
Gondokoro..	4 45	1054	5 years' observations.
Mouth of the Sobat River.	9 30	827	2_{12} " "
Kodok..	10 00	689	$5\frac{3}{12}$ " "
Dueim...	14 00	199	4 " "
Khartoum	16 00	107	7 " "

This regularity however is not maintained in Abyssinia on account of the orographical features of this region. In place of the flat plains of the Sudan with only a few isolated granite or sandstone hills, Abyssinia is a high plateau about 1000 kilometres long and from about 250 to 500 kilometres broad; it has an average altitude of about 2500 metres on the east, where it falls abruptly to the low lands which separate it from the Red Sea, while to the west it slopes at first gently to an altitude of 1800 metres to 2000 metres at the western side of lake Tsana and then falls more rapidly in a series of cliffs and wooded spurs to the Sudan plains which lie at a level of about 500 metres.

This high plateau with its mountain peaks considerably modifies the normal tropical conditions of climate such as exist at a short distance to the west-ward, on the Sudan plains. The rainfall is considerably heavier than on the plains, and the winds during the rainy season are deflected towards the centre of the plateau in the day time when the rain mostly falls.

The decrease of the rainfall from west to east is shown below where a series of places is arranged according to their latitudes.

16° N		14° N		9° N	
Place.	mm.	Place.	mm.	Place.	mm.
Khartoum	107	Dueim..	199	Doleib Hilla ..	827
Kassala	296	Wad Medani ..	419	Nasser..	768
Keren..	640	Gedaref	450	Addis Abbaba ..	121.)
Asmara	417	Adua	850		

Over the greater part of the Abyssinian area no observations have been taken and at the few places where they have been they usually extend over a few months only.

Bruce[1] in 1770 and 1771 measured the rainfall in these two rainy seasons and kept a regular record of pressure, temperature, and winds from 1st January 1770 to the end of May 1771. In 1831-33 Eduard Rüppel[2] travelled in Abyssinia and observed from 19th September to the 17th December 1831, and from 20th January 1832 in Massaua, two months in Halai, from 8th July to the 4th October 1832 in Entchetkab, and from 15th October to 30th April 1833 in Gondar. Antoine d'Abbadie took observations at Gondar from 1st July to the 13th October 1838; he also published[3] six years observations on the thunderstorms of Abyssinia.

From 1839 to 1843 the expedition of Lefèbvre[4] worked in Abyssinia their observations included pressure, temperature, humidity, wind and rainfall.

11 May	—	5 June 1839...	Massaua
9 July	—	19 July 1839...	Adua
25 „	—	28 December 1839	Massaua
6 June	—	17 September 1841	Adua
30 March	—	20 April 1842	Atebi
24 April	—	15 May 1842...	Tchelmekot
25 June	—	5 October 1842	Adua

From 1840-42 Ferret and Galinier were in the country and in the account of their mission[5] they give observations for temperature and rainfall.

Major Harris' political mission to Shoa[6] in 1841-2 took observations of temperature and wind from August 1841 until July 1842 and recorded the number of rainy days in each month at Ankober.

In 1861 Theodor v. Heuglin with Steudner, Hansal and Schubert, spent the rainy months of July, August, September and October at Keren and took regular observations of pressure, temperature, humidity wind and rainfall.[7]

In 1865 an English mission, consisting of Rassam, Prideaux, and Blanc, was sent to King Theodore and was by him kept in confinement at Magdala till released by the expedition of 1868. Blanc kept records of the meteorological conditions throughout his journey and from 12th July, 1866, till 7th April 1868 at Magdala observed the temperature,

1 Travels to discover the source of the Nile, 2nd Ed. London, 1805, Vol. V, p. 407 ff., and Vol. VII, 1 ff.

2 "Reise in Abessinien" 1831-33. Frankfurt-a. M. 1838.

3 "Observations relatives à la Physique du Globe faites au Brésil et en Éthiopie," Paris, 1873.

4 "Voyage en Abyssinie," Paris, Vol. III, p. 159-199.

5 "Voyage en Abyssinie", Paris, 1847, Vol. III.

6 The Highlands of Ethiopia, London, 1844, Vol. III, p. 397.

7 "Reise nach Abessinien," Gera, 1874, p. 104.

wind and weather four times daily. His results are given in the account of the expedition.[1] Rohlfs[2] also published data taken during this expedition.

The whole of the foregoing data have been ably discussed and summarized by R. Nordmann[3] while Dove[4] also utilises them, as well as others for Roseires and places on the Sudan plains which we owe to Russegger.

In recent years more observations have been accumulated but a considerable number of them have not yet been published.

For Massaua and Assab a useful discussion of their climate is due to Petella,[5] and since then observations have been taken but appear to have been published in part only. In 1902 Tancredi published a very full account of the climate of Addi Ugri (lat. 14°55′ N.)[6] utilising data of 1894, 1895 and 1899-1902. At Addis Abbaba members of the staff of the different European representatives have taken observations which enable us to compare fairly satisfactorily data from 1900 to the present time for temperature, pressure, humidity, rain and wind. The Italian stations of Ginda, Massaua, Addi Ugri, Asmara, Chenafena, are now furnishing data for the northern area. In the south very few observations have been made; at Lugh Dr. Ferrandi[7] observed from January 1896 to February 15, 1897 and the Bottego expedition[8] furnishes most valuable information for the southern part of Kaffa; Cecchi[9] too between 1878 and 1881 when crossing the country from Zeila to Kaffa, Gojam and Shoa added to the existing stock of material. For the rainy season Michel's [10] account of the summer rains at Gore is most instructive. Besides this there are numerous isolated observations of different travellers, but most of these fall in the fine, dry season and consequently are of only comparative interest. Since 1900 the Survey Department has established several stations in Upper Egypt and the Sudan. from which observations are available, but the series though of considerable value are as yet too short to furnish accurate normal values.

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1 A history of the Abyssinian Expedition, Clements R. Markham, London, 1869.
2 "Im Auftrage seiner Majestät des Königs von Preussen mit dem englischen Expeditionskorps in Abessinien."
3 "Das Klima von Abessinien," Marburg, 1888.
4 "Kulturzonen von Nord-Abessinien," Pet. Mitt. Erganzungsheft No. 97.
5 Rome, 1894.
6 Boll. Soc. Geog., Rome, February 1903, see also Boll. Agric. Eritrea, Sept. 1905,
7 Lugh. Rome, 1902.
8 L'Omo, Vannutelli, and Citerni, Milan, 1898.
9 "Da Zeila alle frontiere del Caffa," Rome, 1887.
10 "Vers Fachoda," Paris, 1902, p. 530-1.

The temperature of the summer months is mild and even cold at the higher altitudes, so that the oppressive damp heat of a rainy season in the low latitudes is not experienced; but though this is true of the greater part of Abyssinia, the low lying country at the foot of the plateau and the deep ravines of the main rivers, with their rank vegetation, present typically tropical conditions, and by their sheltered position maintain them throughout the year. The hot and dry NE. trade-winds which sweep over the plains of Egypt and the Sudan during most of the year, cannot penetrate into these valleys which, like those of the Abai, and Takkazze run from east to west, and at the foot of the western escarpment the dense woods and bamboo jungle prevent rapid evaporation from the ground, though at a short distance away, west of Gallabat for example, the desert steppes commence.

For the detailed examination of the Abyssinian climate no long series of observations are available, though some extending over two or three years are available for several places. Besides these, travellers furnish numerous isolated observations which, though of less value, aid in furnishing a picture of the climate.

The localities are given in the following table :—

METEOROLOGICAL OBSERVATIONS TAKEN IN AND ROUND ABYSSINIA.[1]

Place.	Lat. N.	Alt.	Observations.	Date.	Reference.
		m.			
Suakin ...	19° 5'	5	Temperature, Rain, Wind ...	1890-1904	Survey Dept.
			Pressure	1902-1904	do.
Tokar	18 28	19	Temperature, Rain, Wind ...	....	Egyptian Army.
Berber ...	18 1	350	Pressure, Temperature, Humidity, Wind ...	1901-1904	Survey Dept.
Keren	15 47	1460	Pressure, Temperature, Humidity	July-Oct. 1860	v. Heuglin.
			Temperature, Rain	Sep. 1890-April 1896	Italian.*
Massaua ...	15 37	19	Pressure, Temperature, Humidity, Rain, Wind	May 1885-Apr. 1893	Petella. Italian.
Asmara ...	15 20	2372	Temperature, rain ...	Sep. 1890-July 1891 May 1894-Apr. 1895	Italian.
			Pressure, Temperature	Mar. 1901-Jan. 1902 and 1904	
Khartoum ...	15 40	385	Pressure. Temperature, Rain, Humidity, Wind.	1900-1904	Survey Dept.
Kassala ...	15 31	580	Temperature, Rain	Nov. 1894-June 1895	Italian. *
Halai	15 00	2563	Temperature, Rain.	May-Decem. 1894	do. *
Addi Ugri ...	14 53	2022	Temperature, Humidity, Rain, Wind, ...	Apr. 1894-Dec. 1895 Jan. 1899-Dec. 1904	do. *
			Pressure	Jan. 1902-Dec. 1904	do. *

[1] Up to December 1904 only.

METEOROLOGICAL OBSERVATIONS TAKEN IN AND ROUND ABYSSINIA.—*continued*,

Place.	Lat. N.	Alt.	Observations.	Date.	References.
		m.			
Wad Medani	14° 24'	410	Temperature, Humidity, Rain, Wind.	Jan. 1901-1904	Survey Dept.
			Pressure	Jan. 1902 1904	do.
Intetshau ...	14 20	..	Rain	....	....
Adua	14 10	1910	Temperature, Rain, Wind	June-Sept. 1841 July-Sept. 1842	Lefébvre.
Gedaref ...	14 3	..	Rain	1903-1904	Survey Dept.
Enchetkab .	13 6	2960	Temperature	July-Sept. 1832	Rüppell.
Gallabat ...	12 57	..	Rain	1903-1904	Survey Dept.
Gondar ...	12 36	1910	Temperature, Rain ...	Feb. 1770-May 1771 d'Abbadie 1838	Bruce.
Nocra	15 43	5	Temperature, Rain	Jan. 1893- Dec. 1894	Italian. *
Assab	12 59	6	Temperature, Rain	May 1893 Feb. 1896	do. *
Chenafena ...	11 48	1631	Pressure, Temperature, Rain.	April. Dec. 1902-4	do. *
Roseires ...	12 00	450	Rain	1900 and 1904	Survey Dept.
Ginda	15 26	962	Temperature, Rain ...	Aug. 1891-Apr. 1895 and 1904	Italian. *
Magdala ...	11 23	2760	Temperature, Rain, Wind...	July 1886-Apr. 1888	Blanc.
Ankober ...	9 35	2500	Temperature, Rain, Wind...	Aug. 1841-July 1842	....
Addis Abbaba.	9 2	2440	Pressure, Temperature, Humidity, Rain, Wind	Nov. 1901-1904	.... *
Gore	8 00	2100	Temperature, Rain, Wind ...	1897	Michel.
Lugh	3 10	268	Temperature, Wind, Rain ...	Jan. 1895-Feb. 1896	Ferrandi.
Asmara ...	15 20	2372	Pressure, Temperature, Rain	May 1901-Jan. 1902 and 1904	Italian. *

* Taken at Stations established by the Italian Government in Eritrea and kindly communicated by the Observatory of Rome or from the Bolletino Agric. Eritrea.

The great difference which exists between the altitudes of different parts of Abyssinia and the plains which surround it, gives rise to marked differences of climate at places which geographically are but little distant from one another; from the higher summits of the Simien Mountains one may leave a region but little below that of perpetual snow, passing through the temperate climate of the main plateau and finally within a few hours have descended into the hot damp tropical climate of the Takazze valley.

The Abyssinians distinguish three types of country according to their different altitudes, and to each of these belongs a corresponding climate; these are:—

1. Qolla or lowland extending from sea level to a height of 1800 metres;

2. Woina Dega or wine-highland (a transition region between the Qolla and the Dega) 1800-2400 metres;

3. Dega or highland, the part which rises above 2400 metres.

The Qolla includes the belt of country on the western slopes of the plateau, between it and the arid plains of the eastern Sudan, as well as the valleys of the principal rivers; Dove [1] would include also the basin of lake Tsana.

The Woina Dega forms the greatest part of the Abyssinian plateau since the mountain masses of the Dega are confined to Simien, Mount Guna, and the Chok mountains in Gojam and a few other localities.

The low country between the plateau and the Red Sea known as the *Samhar* is climatologically distinct from the rest of the Abyssinian area since it has winter rains, instead of the summer monsun rains of the rest of the country.

Temperature.—The highest temperature is met with on the plains of the Sudan and here we find also the greatest range of temperature since the dry clear air allows rapid radiation at night. In the Samhar high temperatures also occur but the air is damp from the proximity of the sea and the range is much less. Wad Medani on the Blue Nile, and Massaua on the Red Sea are typical stations of these two areas.

Wad Medani. (1902-1904).

LAT. 14° 24′ N. LONG. 33° 31′ E. ALT. 410 METRES.

	Mean	Mean Maximum	Mean Minimum	Range
	C°	C°	C°	C°
January...	21·6	34·1	15·0	19·1
February	23·6	35·5	15·1	20·4
March	27·0	39·7	18·0	21·7
April	30·2	41·9	23·1	18·9
May	**32·3**	**43·4**	24·9	18·2
June	31·1	41·6	23·7	17·8
July	28·6	38·7	21·8	16·9
August	27·7	38·3	21·6	16·7
September	28·0	39·6	23·7	15·9
October	29·3	41·2	22·3	17·9
November	27·2	39·1	20·7	18·4
December	23·2	35·9	16·3	19·6
Year	27·5	39·1	20·6	18·5

Pet. Mitt. Erganzungsheft, No. 97. Gotha, 1889.

Massaua. (May 1885-April 1893.)[1]

LAT. 15° 36′ 40 N. ALTITUDE. 19·5 METRES.

	Mean	Mean Maximum	Mean Minimum	Range
	C°	C°	C°	C°
January..	25·6	28·9	22·5	6·4
February	26·0	29·6	23·0	6·6
March	27·2	30·6	24·1	6·5
April	29·0	32·5	25·8	6·7
May	31·3	34·7	28·0	6·7
June	33·5	37·5	29·6	**7·9**
July	**34·8**	**38·7**	**31·6**	7·1
August	34·7	38·6	31·4	7·2
September	33·3	36·5	29·9	6·6
October	31·7	35·0	28·2	6·8
November	29·9	32·1	25·5	6·6
December	27·0	30·5	23·2	7·3
Year	30·3	33·8	26·9	6·9

The fall of temperature at Wad Medani in June-September during the summer rains is not experienced at Massaua where the maximum is reached in July and the lowest temperature coincides with the winter rains of January, since there is no rain in the summer months on the Red Sea coast.

At Assab conditions similar to those of Massaua prevail, but the observations there do not form so long or so complete a series.

Assab.—LAT. 12° 59′ N., ALTITUDE 6 METRES.[1]

	Monthly Mean	Mean Max.	Mean Min.	Range	
	C°	C°	C°	C°	
January	* 25·6	28·2	22·7	5·5	(* for 1886 and 1887.)
February	* 25·7	28·3	22·6	5·7	(† for 1885, 1886 and 1887.)
March..	* 27·7	30·0	24·1	5·9	(‡ for 1885, 1886.)
April	* 28·6	31·9	25·0	6·9	
May	* 30·4	34·4	25·2	7·2	
June	* 33·2	37·2	27·3	**9·9**	
July	† **35·5**	**39·3**	**30·1**	9·2	
August...	† 35·0	38·9	29·6	9·3	
September	† 33·8	36·3	29·0	7·3	
October	‡ 30·2	33·2	26·2	7·0	
November	‡ 27·4	30·2	24·2	6·0	
December	‡ 25·5	28·2	21·8	6·4	
Year	29·9	33·0	25·7	7·2	

[1] Petella, Massaua ed Assab. Rome, 1894.

In the Qolla region there are few places where a long series of observations have been made. Isolated observations at Roseires, and Gallabat are available; more regular ones for Keren in the north, in the basin of Anseba river at an altitude of 1460 metres, exist, and also at Ginda about 50 kilometres south-west of Massaua and at an altitude of 962 metres, but even at Keren we are nearing the upper limits of the Qolla region.

Keren (1892 and May 1894.—April 1895).

LATITUDE 15° 46′ 44″. ALTITUDE 1460 METRES.

	Monthly Mean.	Mean Maximum.	Mean Minimum.	Range.
	C°	C°	C°	C°
January	18·3	25·1	13·6	11·5
February..	19·2	—	—	—
March	21·9	29·2	14·1	15·1
April..	23·4	27·7	16·3	11·4
May	**25·6**	**31·2**	**18·6**	12·6
June..	22·8	26·2	15·4	10·8
July	20·6	23·2	14·0	9·2
August	18·9	20·3	15·3	5·0
September	19·6	24·5	13·9	10·6
October	19·9	25·3	15·1	10·2
November	19·6	26·4	15·2	11·2
December	18·6	25·9	14·0	11·9
Mean..	20·7	25·9	15·0	10·8

Ginda (August 1891.—April 1895).

LATITUDE 15° 26′ 13″. ALTITUDE 962 METRES.

	Monthly Mean.	Mean Maximum.	Mean Minimum.	Range.
	C°	C°	C°	C°
January	18·3	22·2	14·4	7·8
February..	19·6	22·7	16·3	6·4
March	20·5	23·4	17·4	6·0
April..	24·0	28·0	19·9	8·1
May	26·9	31·3	22·5	8·8
June..	29·4	**34·6**	24·2	**10·4**
July	**29·6**	34·1	**25·2**	8·9
August	28·1	31·6	24·5	7·1
September	28·3	33·5	23·8	9·7
October	24·9	29·5	20·1	9·4
November	22·0	26·8	18·8	8·0
December	20·2	23·5	16·7	6·8
Mean..	24·4	28·4	20·3	8·0

It is to be noticed that in spite of the difference of 500 metres in altitude the mean temperatures of Keren and Ginda are nearly the same from December to May, but in the other months that of Ginda is considerably higher. This is due to the winter rains at Ginda which are heavy while in July and August there is only a secondary maximum. The range of temperature at the time of the summer rains is very small so that the mean of the year stands about 4° higher than that of Keren.

Dove would include the basin of lake Tsana in the Qolla regarding it as a transition from this to the Woina Dega. For this part of the country there exist the observations of Bruce from February 1770 to May 1771, of A. d'Abbadie and Rüppel (Met. Zeit. 1876, p. 170) at Gondar.

	Monthly Mean [1]	Monthly Mean [2]	Mean Max. [1]	Mean Minimum.	Range.
	C°	C°	C°	C°	C°
January	20·0	19·4	23·3	16·1	7·2
February	20·6	20·0	24·4	13·9	10·5
March	21·9	22·1	29·5	13·3	16·2
April	**23·4**	**22·7**	**32·8**	15·0	**17·8**
May	21·6	20·8	27·2	15·0	12·2
June	17·8	18·9	20·0	**15·6**	4·4
July	15·4	16·9	18·9	12·8	6·1
August	14·8	17·0	17·8	12·8	5·0
September	16·9	19·4	21·1	13·3	7·8
October	17·4	19·0	21·1	13·3	7·8
November	18·7	18·6	23·3	15·0	8·3
December	19·4	17·6	23·3	15·0	8·3
Mean	19·0	19·4	23·6	14·3	9·3

On the plateau of Abyssinia which comprises the greater part of the country two localities ranged along the eastern margin furnish representative data of the Woina Dega. Addi Ugri (lat. 15° N.) on the north and Addis Abbaba in the south provide the most complete series of meteorological observations, while Adua and Gondar are characteristic of the central and northern part of the plateau. The observation of Addi Ugri up to December 1904 have been very fully discussed by Tancredi. [3] Those of Addis Abbaba are due to members of the British, French, Italian and Russian staffs residing at the court of the Emperor Menelik.

[1] Bruce.
[2] D'Abbadie and Rüppell.
[3] Soc. Geog. Ital., February, 1903. Rome, p. 76, also Boll. Agric. Eritrea, Sept. 1905.

Addi Ugri. (April 1894, December 1895 and 1899-1904).
LATITUDE 14° 53'.—ALTITUDE 2022 METRES.

	Monthly Mean.	Mean Maximum.	Mean Minimum.	Range.
	C°	C°	C°	C°
January	18·1	25·6	11·3	14·3
February..	19·0	27·4	11·8	15·6
March	21·3	29·8	13·6	16·2
April..	21·3	29·4	13·8	15·6
May	21·5	28·9	15·2	13·7
June..	20·9	27·4	14·4	13·6
July	18·2	23·5	13·1	10·4
August	17·9	23·0	13·1	9·9
September	19·6	25·5	13·6	11·9
October	19·3	27·0	12·9	14·1
November	18·3	25·9	11·6	14·3
December	17·4	25·4	10·4	15·0
Mean	19·4	26·6	12·9	13·7

Addis Abbaba. (July 1898—December 1904).
LATITUDE 9° 0'.—ALTITUDE 2440 METRES.

	Monthly Mean.	Mean Minimum.	Mean absolute Maximum	Mean absolute Minimum	Range.
	C°	C°	C°	C°	C°
January	16·6	7·2	22·9	4·2	18·7
February..	15·2	8·6	23·1	5·4	17·7
March	**17·8**	10·0	**24·4**	6·0	18·4
April..	16·2	**10·2**	22·9	8·0	14·9
May	17·3	9·6	23·7	7·0	16·7
June..	15·1	9·8	22·0	8·0	14·0
July	13·7	10·0	20·2	**8·1**	12·1
August	14·9	10·0	19·8	7·8	12·0
September	14·4	9·8	20·3	7·9	12·4
October	15·6	8·4	22·0	5·6	16·4
November	16·3	6·8	22·0	4·0	18·0
December..	15·6	6·9	21·7	3·7	18·0
Mean	15·7	8·9	22·1	6·3	15·8

For Adua we have two short series of observations taken by Lefèbvre in the rainy season of 1841 and 1842.

Adua.—LATITUDE 14° 10' N. ALTITUDE 1910 METRES.

	1841	1842	Mean.
	C°	C°	C°
June	22·6	—	22·6
July	20·6	20·3	20·4
August	19·7	19·6	19·6
September	19·2	19·6	19·4

From the Dega or hill-country we have observations from five stations nearly all on the eastern edge of the plateau, viz.

	Latitude.	Altitude
		metres
Asmara	15° 20′ 27″	2372
Halai	14 59 42	2565
Entchetkab	13 6	2960
Magdala.	11 23	2760
Ankober.	9 35	2500

MEAN MONTHLY TEMPERATURE.

	Asmara.	Halai.	Entchetkab.	Magdala.	Ankober.
	C°	C°	C°	C°	C°
January	15·4	—	—	13·7	11·0
February	15·6	—	—	14·4	12·6
March	16·8	—	—	16·4	14·0
April	16·7	—	—	17·4	12·9
May	17·0	14·7	—	**19·0**	15·4
June	**18·2**	**14·8**	—	17·4	**16·7**
July	16·3	12·0	—	15·2	14·5
August	16·3	10·5	11·6	14·9	13·2
September	16·8	10·1	11·4	15·2	12·9
October	14·0	7·9	12·1	13·8	11·2
November	14·6	13·4	—	13·2	11·1
December	15·0	13·7	—	13·4	11·0
Mean..	16·1	—	—	14·5	13·0

Asmara.

May, 94-April, 95, March, 01-Jan., 02.

	Mean Maximum.	Mean Min. (94-95).
	C°	C°
January	25·1	6·8
Februory	22·8	7·2
March	24·4	8·4
April	23·8	7·9
May	25·0	8·7
June	**25·3**	**11·5**
July	22·0	10·1
August	21·0	11·2
Septemb.	22·6	11·1
October	20·0	10·9
November	20·8	10·9
December	21·4	6·9
Mean ..	22·9	9·3

Halai

May-December, 1894.

	Mean Maximum.	Mean Minimum.	Range.
	C°	C°	C°
January	—	—	—
February	—	—	—
March	—	—	—
April	—	—	—
May	24·2	5·2	19·0
June	25·0	4·6	19·0
July	20·6	3·5	17·1
August	17·6	3·5	14·1
Septemb.	16·4	3·8	12·6
October	14·1	1·8	12·3
Novemb.	19·7	7·1	12·6
Decemb.	21·6	5·8	15·8
Mean..	19·9	4·4	15·4

1 From Nordmann, "Das Klima von Abessinien."

Magdala.[1]

	Mean. Maximum.	Mean Minimum.	Range.
	C°	C°	C°
January.	21·4	5·5	15·9
February	23·3	6·9	16·4
March	25·8	8·9	16·9
April	28·0	8·3	**19·7**
May	27·8	**10·5**	17·3
June	**28·3**	9·4	18·9
July	23·3	8·3	15·0
August	24·1	8·6	15·5
Septemb.	20·8	7·5	13·3
October	21·4	6·6	14·8
Novemb.	21·7	3·2	18·5
Decemb.	22·0	3·2	18·8
Mean..	23·7	7·2	16·8

Ankober.[2]

	Mean Maximum.	Mean Minimum.	Range.
	C°	C°	C°
January	14·6	7·5	7·1
February	15 5	9·2	6·3
March	17·1	10·8	6·3
April	15·0	10·7	4·3
May	18·0	12·8	5·2
June	**19·0**	**14·4**	4·6
July	17·0	11·9	5·1
August	15·9	10·0	5·9
Septemb.	15·6	10·3	5·3
October	14·2	7·9	6·3
Novemb.	14·3	7·8	6·5
Decemb.	14·7	7·0	7·7
Mean..	15·9	10·1	5·9

Place.	Yearly Mean.	Mean Maximum.	Mean Minimum.	Mean Range.	
	C°	C°	C°	C°	
Wad Medani.. ..	27·5	39·1	20·6	18·5	Sudan.
Suakin	27·6	33·1	23·8	9·3	Samhar.
Massaua..	30·3	33·8	26·9	6·9	„
Assab	29·9	33·0	25·7	7·2	
Ginda	24·4	28·4	20·3	8·0	
Keren	20·7	25·9	15·0	10·8	Qolla.
Gondar	19·2	22·7	14·8	9·3	„
Addi Ugri	19·3	26·8	12·8	14·3	Woina.
Addis Abbaba ..	15·7	—	8·9	—	Dega.
Asmara	16·0	22·9	9·3	13·6	„
Magdala..	15·3	23·7	7·2	16·5	„
Ankober.. . ..	13·0	15·9	10·1	5·8	„

The difference between the mean maximum temperature of Magdala and Ankober needs explanation.

To review the temperature conditions of the Abyssinian plateau compared with those of the surrounding country, it may be said that owing to its elevation it enjoys a mild climate with a moderate range of temperature as compared with the lower lying Sudan plains where the mean maximum temperature for the year is 39° 8′, and the mean range is 18° 2′; on the eastern side near the Red Sea the mean temperature is higher than on the plains owing to the much higher mean minimum and the mean range falls to 6°.9.

[1] The Abyssinian Expedition, Markham, App, C.

[2] The Highlands of Ethiopia. Harris. Vol. II, App. I.

In the Qolla region hot damp conditions with small range prevail and the two stations quoted, Ginda and Keren do not fairly represent the conditions which exist in the Abai and the Takazze valleys. Gondar, Addi Ugri, and Addis Abbaba are representative of the greater part of Abyssinia, though the first named station is probably affected by the proximity of lake Tsana, as is seen in the reduced maximum and range and the increased minimum. The three mountain stations are confined to the eastern crest of the plateau. In all cases except in the Samhar region, there is a maximum about May, which is followed by the cooler period of the rainy season, after which there is another secondary maximum about November.

Winds.—The winds of the Abyssinian area in general show a variation between the dry and the rainy season just as the other meteorological factors do, but besides this there is a considerable difference between the directions of the prevalent winds in various parts of the country at the same time of year. Observations covering a complete year are not numerous, especially in the central and southern parts of the plateau, and consequently many isolated or incomplete data have to be utilised.

Normally, the NE. trade wind sweeps over the deserts of the Sudan from October to May and blows up to the Abyssinian plateau as a N or NW. wind; about May southerly winds set in as the sun increases its north declination, and these continue after the solstice as it returns southward until near the autumn equinox. This period of southerly winds coincides with the rainy season. The effect of this monsun or half-yearly reversal of the wind is traceable as far as Suakin.

Suakin.—Wind.

Percentage days of predominant wind for different months for 10 years, 1891-1900.

Wind	N	NE	E	SE	S	SW	W	NW	Calm	Variable
January	35·0	36·6	2·7	0·8	—	0·3	1·9	21·9	—	0·6
February	33·6	35·5	3·8	1·3	—	—	0·4	22·9	—	2·4
March	32·1	33·0	7·7	0·7	—	0·7	1·4	24·0	—	.0·4
April.	39·8	37·9	2·5	2·2	—	—	2·3	15·3	—	—
May..	39·6	36·5	9·3	2·3	0·4	0·4	0·4	9·0	—	2·2
June	17·0	34·1	10·8	1·3	3·9	4·1	12·0	12·2	—	4·6
July..	12·2	10·9	5·0	0·8	4·5	29·3	11·7	14·9	—	10·6
August	11·6	17·2	3·6	2·0	7·9	19·2	7·0	11·8	—	19·7
September	31·0	40·6	7·4	—	5·9	1·8	4·4	3·7	—	5·2
October	49·5	28·1	8·6	1·9	0·1	—	4·8	0·2	—	6·8
November	47·5	32·0	3·4	1·4	—	—	2·0	9·1	—	4·7
December.	43·4	30·5	7·9	1·1	—	—	5·4	9·3	—	2·5
Mean.	32·7	31·1	6·1	1·3	1·9	4·6	4·5	12·9	—	5·0

Tokar.—PREVALENT WINDS.

DATE	Jan.	Feb.	March	April	May	June	July	August	Septem.	October	Novem.	Decem.
1892	..	..	..	..	..	..	..	..	WSW	ENE	ENE	NE
1893	N	NE	NE	NE	NE	NE SW	SW	SW	SW NE	ENE	E	ENE
1894	NNE	NNE	NE	NE	NE	SW	SW	SW	SW NE	NE	ENE	NE
1895	NE	NNE	NE	NE	NE	SW NE	SW	SW	SW NE	NNE	NNE	NE
1896	NNE	NNE	NE	NE	NE	..	..	..	..	..	NE	NE
1897	NNW	NNW	NNW	NW	W	SSW SW	S	S	S	NNW	N	NNE
1898	N	N	N	N	N	WNW	SW	SSW	WSW	NNE	..	..

The winds of these two stations are interesting as they are the furthest extension northward of the southerly winds and do not show so much deflection to NW. and NNW. in the rainy season as is recorded at most stations in north Abyssinia, *e.g.* Addi Ugri. As far as Tokar (lat. 18° 12′ N) the SW. winds prevail for 3 months but at Suakin it is only in July and August that the southerly and south-westerly winds are predominant.

The high mass of the Abyssinian plateau considerably complicates the simple half-yearly alternation of the winds at places within its borders and the regular change from southerly to northerly winds, and again from northerly to southerly often cannot be readily recognised. The plateau occupies an area of low barometric pressure in the earlier months of the year, but after May it lies in the western part of the trough of low pressure which extends from Central Asia as far as the Nile valley (see Plate XLV.).

At Addi Ugri NE., E., and SE. winds of the dry season are replaced by W. and NW. winds in the rainy season, and at Adua, SW., and NW. winds prevail during these months. Addis Abbada, Magdala and Ankober on the eastern side of the plateau also show the same seasonal change of the winds; January to May SE., and E. winds prevail while NE. and ENE. winds blow in October, November and December. At these stations in the rainy season the winds are variable usually NNE. on the fine days, while SW. winds accompany the heavy falls of rain which at this season occur almost daily.

At places like Gondar and other parts of the basin of lake Tsana, the land and lake breezes probably mask the true movement of the lower air currents, and similarly the mountain and valley winds on the western slopes of the plateau above Gallabat and other such places will produce alternations of local winds which are not included in this general statement.

At Moger on the south side of the Rogge Mountain, and therefore just out of the basin of the Guder and in that of the Omo, Cecchi[1] stayed from July 22 till the September 30, 1878 but as he was in the neighbourhood of this place from the beginning of July until the end of November we may take these observations as representing a rainy season. From February 21, to October 3, 1879, he was at Shalla, (Lat. 7° 44′ N., Long. 36° 26′) situated at an altitude of about 2100 metres on the east side of the Sekia and Gesha mountains in or near which the Didessa, the Baro and the Gogeb, the most important tributaries of the Blue Nile, the Sobat, and the Omo, respectively, take their rise. These two series furnish a good record of the winds of this important gathering ground.

PREVALENT WIND.

	July. 22–31	August.	September.	October.
Moger* 1878	SW	SW	NW-SE	Variable
N° of observations	63	131	216	152
N° of calms	15	36	68	74

	March.	April.	May.	June.	July.	August.	Sept.
Shalla† 1879 ..	SSE	SW	SSE	S	SSE	S	Var.
N° of observations	26	20	88	17	107	119	126
N° of calms.. ..	20	8	54	10	82	93	81

* 70 km. SW. of Addis Abbaba. † Near the source of the Baro.

At Lugh or near Lake Stephanie beyond the southern extremity of Abyssinia a similar alternation occurs, N. and NE. winds prevail from November to March, variable winds in October and April, and S. and SW. winds from May to September.

The wind directions at Lugh are given by Ferrandi[2] and are of special interest. Situated on the low plain of Somaliland it is in the current of the Indian south-west monsun and consequently has a steady SW. wind from May to September. This seems to be about its western limit, for the members of Bottego's expedition[3] who were travelling west of Lugh from January to September 1896 between the river Webi and Lake Rudolf recorded only light to moderate winds from SE. during these months.[4] West of this point there are no observations in the rainy season until we come to Gore on the Baro river where

[1] "Da Zeila alle frontiere del Caffa." Rome, 1887, Vol. III, p. 575, 599.
[2] Lugh. Rome, 1903.
[3] L'Omo. Vannutelli and Citerni. Milan, 1899.
[4] Shown under heading of Lake Stephanie on p. 196.

Michel[1] made observations for several months in 1897, and gives the predominant wind direction as westerly.

From Beni Shangul there is little information; Schuver who travelled in this part during the rainy season of 1881 says that near Fadasi rain, accompanied in most cases by thunderstorms, came up usually from the west or south-east, but as a rule the winds were light and calms predominated;[2] he was inclined to think that the winds were light throughout the year.

Major Gwynn passed through the same district December 1899-March 1900 and writes, "on the low ground, which was pretty thickly wooded, the wind was practically imperceptible; generally I should say that the wind was very light, and variable in direction." On the Lega Galla plateau east of the Yabus he notes that the wind was very light in February and generally from the south-west. It seems probable that this was a valley wind blowing during the day up to the high Lega Galla plateau, situated at 1500 to 1800 metres above the sea.

At Roseires the rains at the end of May are accompanied by south-west winds, and southerly winds predominate throughout the summer months.

PERCENTAGE FREQUENCY OF WINDS AT ADDIS ABBABA 1900-1904.

MONTHS	N	NE	E	SE	S	SW	W	NW	Calm	MEAN DIRECTION
January ..	5	30	24	7	9	2	3	1	20	N 76° E
February ..	10	12	22	13	9	4	8	4	19	E
March.. ..	11	34	18	8	7	2	2	0	18	N 65° E
April	7	23	23	12	11	2	1	2	19	S 85° E
May	5	30	22	10	12	0	0	0	20	N 82° E
June	12	26	17	5	15	1	2	0	24	N 75° E
July	13	31	12	3	13	15	3	2	9	N 65 E
August ..	15	33	2	4	16	16	5	3	·6	N 45 E
September..	4	60	7	6	12	3	1	0	6	N 61° E
October ..	3	59	15	10	6	0	0	1	6	N 64° E
November..	4	48	10	11	11	2	0	1	12	N 71° E
December..	4	34	18	11	15	0	0	1	16	N 84° E

ROSEIRES, WIND DIRECTIONS OBSERVED 1905.

MONTHS	N	NE	E	SE	S	SW	W	NW	Calm
May	6	1	1	2	38	8	1	4	1
June	0	4	2	2	42	5	3	0	2
July	4	0	4	2	41	3	2	1	5
August . ..	8	0	5	7	37	3	2	0	0
September ..	6	1	7	5	37	3	0	0	1

[1] Vers Fachoda, Paris, 1900.
[2] Pet. Mitt. Erganzungsheft 72. Gotha, 1883, pp. 9 and 41.

PREVALENT WINDS OF ABYSSINIA.

PLACE	January	February	March	April	May	June	July	August	Septem.	October	Novem.	Decem.
Suakin[4]	NNW	N	NNE	NNE	NNE	NNE	W	W	NNE	N	N	N
Tokar[4]	NNE	NNE	NE	NNE	NE	NE SW	SW	SW	WSW	NNE	NE	NE
Assab[3]	SE	SE	SE	SE	SE NW	N	NW	N	SE	SE	SE	SE
Addi Ugri[2]	NE	E	SE	SE	E	W	W	NW	NE	NE	ENE	ENE
Adua[1]	—	—	—	—	—	NW SW	NW SW	NW SW	NW	—	—	—
Lake Tsana plain[6].	S SE SW	S SW	S SW	S SW	NE E	NE	—	—	—	—	—	—
Magdala[1]	ESE	SE	NNE Var. SSE	NE Var SE	Var.	Var.	SW	SW	SW	N NE	N NE	N NE
Ankober[9]	E ESE	E SE	E	E	E	E	Var. SE SW	Var. SE SW	NE	NE	NE	E
Addis Abbaba[5]	NE	NE	E	E	E	NE SW	NE SW	NE	NE	NE	NE	ENE
Go..e and Wallega[8]	—	—	NE	NE	NE SE	W	W	W	—	—	—	—
Near Stephanie Lake..	E	NE	NE	E	Var.	SE	SE	Var.	S	—	—	—
Lugh[7]	NE	N	E	SE	SW	SW	SW	SW	SW	Var.	E	NE

[1] Nordmann, "Das Klima von Abessinien."
[2] Tancredi, Boll. Soc. Geog. Ital. 1908.
[3] Petella, Massaua e Assab.
[4] Sur. Dept. Obs.
[5] Nicolas Obsy.
[6] Blanc, Jour. R. Geog. Soc., 1869.
[7] Ferrandi, Lugh.
[8] Michel, Vers Fachoda.
[9] The Highlands of Ethiopia, Harris, Vol. II, App. I.

Humidity and evaporation are also of interest, but systematic observations are scarce; the Russian observations at Addis Abbaba and the Italian ones at the stations in Eritrea form the bulk of the material available. The high altitude of the table land as well as its position within the region of the NE. trade wind accounts for the dryness of the winter months and it is only in the wet season June-September that the humidity is high at midday.

Addis Abbaba.[1]—RELATIVE HUMIDITY PER CENT.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
7 a.m.	61	71	65	74	61	81	90	88	80	57	57	65
1 p.m.	36	44	42	54	40	64	82	78	66	39	35	23
9 p.m.	49	58	52	66	52	75	88	86	76	46	45	55
Mean	48	58	52	65	51	74	86	84	74	48	45	53

VAPOUR TENSION IN MILLIMETRES.[1]

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	YEAR
7 a.m. ..	6·5	6·9	7·3	7·7	7·6	8·5	9·0	9·1	8·0	5·8	5·6	5·8	7·3
1 p.m. ..	6·8	7·4	7·6	8·9	7·7	9·9	10·9	11·2	9·5	6·8	6·1	6·2	8·2
9 p.m. ..	6·4	6·8	7·1	8·1	7·6	8·7	9·5	9·8	8·6	5·7	5·2	5·9	7·5
Mean ..	6·6	7·0	7·3	8·2	7·6	9·0	9·8	10·0	8·7	6·1	5·6	6·0	7·7

Addi Ugri.—MEAN RELATIVE HUMIDITY PER CENT.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	YEAR
Oct. 1899– Dec. 1904	32	32	28	39	32	38	69	76	55	40	46	40	44

[1] Derived from observations from July 1900 to December 1904 except during July, August and September 1902, and February, April to July and September and October 1903.

The above results may also be collected by years and seasons as in the following table:—

Addi Ugri.—Mean Relative humidity per cent.

Dec. Jan. Feb.	March April May	June July Aug.	Sept. Oct. Nov.	Year.
35	38	58	49	1899
36	32	66	50	1900
42	32	62	51	1901
40	38	58	50	1902
33	24	59	47	1903
26	..	63	41	1904

	1899	1900	1901	1902	1903	1904
Rainy Season. June-September.	52	62	60	..	59	57

Addi Ugri is the only station where a series of measurements of evaporation has been made. They are taken with an evaporimeter placed in a meteorological screen thus fairly representing a free water surface of small area.[1]

Addi Ugri.—Mean daily evaporation in mm. 1899–1904

Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
6·0	6·1	7·8	6·7	8·8	6·5	2·6	2·1	4·9	4·9	5·0	4·9	5·4

These figures would seem to show that the estimate of 4 mm. on lake Tsana from October to May and 2 mm. from June to September is fairly accurate though perhaps a little low.[2]

We now come to the most important climatic factor, the rainfall which feeds numerous tributaries of the Blue Nile, Atbara, Khor el Gash, and Khor Baraka, and furnishes the Nile flood. Of late years information has been greatly increased; numerous travellers have penetrated into southern Abyssinia; measurements of rainfall since 1898 are available from Addis Abbaba, and also from several stations in Eritrea.

[1] Tancredi Boll. Soc. Geog. Ital., Feb. 1903 and Boll. Agric. Col. Eritrea, Sept. 1905.

[2] Dupuis. Report on Lake Tsana, in A Report on the Basin of the Upper Nile. Cairo, 1904.

First, however, the winter rains of the coast must be excepted since they furnish nothing to the Nile supply, but in describing the climate of Abyssinia they cannot be wholly omitted. Assab, Massaua, and Suakin are typical stations and at Ginda on the foot hills of the plateau most of the rain falls in winter though from its proximity to the plateau there is a secondary maximum in July. At Suakin, Massaua and Assab, though there can hardly be said to be summer rains, in some years a small amount of the rain falls in July and August at the time when the south westerly winds reach as far as north as Suakin.

At the time of the summer monsun the rain falls almost exclusively in the afternoon, continuing on into the night in the height of the rainy season. The mornings and forenoons are clear, but about midday clouds form rapidly and soon heavy masses of dark rainclouds appear; thunderstorms are very frequent, accompanied by heavy rain. This is the usual procedure of tropical rainstorms in mountain districts and is easily understood, since the winds blowing up to the mountains during the day carry up the moist air of the low country, so that its moisture condenses on the elevated plateau.

The great rains commence generally on the plateau in June and end before or in October but from April and throughout May rain falls intermittently ; these are the Azmera or light rains.[1]

At Adua and in nearly all the part of Tigre between the Mareb and the Weri except the actual edge of the plateau the rains commence at noon. The wind is from the north and passes round to WNW. This holds for all the Woina Dega ; at high levels, the Dega, the rain is almost continuous, and the season of the rains begins earlier and ends later.[2]

Coming to the basin of the Abai and those of the Takazze, Settit and the Mareb, there are measurements of the rainfall for several places which give a more accurate idea than a verbal description. On examining the average rainfall of Abyssinia and the eastern plains of the Sudan (see p. 211) it will be seen at once that the single rainy season is clearly indicated everywhere. There is however a marked difference between the eastern and western stations, the former have some rain in almost every month, though in November and January it is small in amount, but the latter, Gondar, Adua, Roseires, Gallabat, Gedaref and Kassala have an absolutely rainless climate from the middle of October until the end of April.

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[1] Lefèbvre, "Voyage en Abyssinie," Vol. III, p. 8.
[2] Lefèbvre, "Voyage en Abyssinie," Vol. III, p. 9.

The distribution of the rainfall throughout the year in Abyssinia is as follows:—

In January clear skies and dry rainless weather are the rule throughout Kaffa, Wallega, Beni Shangul, the Sudan plains and most of the plateau of Abyssinia. In the coast region the winter rains are falling as shown by the observations at Assab, Ginda, Massaua, and Suakin, while a small but unimportant amount of rain falls on the eastern crest of the plateau, at Addis Abbaba, Ankober, Magdala, and Addi Ugri.

In February the same conditions are in force except that at Addis Abbaba the rain is heavier.

In March the light rains begin in Kaffa (Gore) near the headwaters of the Sobat and on the Wallega plateau. At Addis Abbaba the early or lesser maximum occurs.

In April some rain falls in the NE. and E. of the plateau of Abyssinia but not yet on the central and western portions. In Wallega and Kaffa there is rain from time to time, and in Beni Shangul the lesser rains commence. The Dabus and Didessa begin to rise, causing the first rise in the upper reaches of the Blue Nile at the end of April or early in May.

In May the southern rains in Kaffa, Wallega and Beni Shangul increase; the first rains fall at Roseires, Gallabat, and the other Sudan stations, and also on the central and western parts of the Abyssinian plateau north of the Abai. In this month at Addis Abbaba is the minimum between the early maximum of March, and the principal maximum in August. All stations have some rain in this month which is considered as the beginning of the rainy season,

In June the Samhar has no rain but it falls heavily at all other places in Abyssinia, and also on the Sudan plains; these conditions continue throughout July and August steadily increasing in strength until the August maximum is reached.

In September there is a marked decrease in the rainfall generally and by October it has almost ceased except in the southern provinces of Wallega and Kaffa. In the coast region the winter rains begin in this month.

In November and December the winter rains of the coast reach their maximum, and the higher stations on the eastern margin of the plateau, Addi Ugri, Addis Abbaba etc. have a slight rainfall. On the Sudan plains dry season conditions have set in and also over the Lake Rudolf plains south of Kaffa.

The most southern station at which rainfall has been measured is Addis Abbaba where several series of observations have been made but none are altogether complete.

Russian observations[1] exist for July 1898–January 1899, June 1900–May 1902, October 1902-March 1903 at Addis Abbaba and for July-September 1902 at Addis Alem.

Italian observations exist for 1903 and 1904.[2]

British observations exist for Feb. 1901–Sept. 1902, July 1903–Dec. 1904.[3]

French observations exist for 1898.[4]

These observations differ slightly, but as no descriptions of the rain-gauges and their exposure are available all the monthly totals are given in the following table and from them mean monthly values have been derived.

MONTHLY RAINFALL IN MILLIMETRES.

Addis Abbaba.—Latitude 9° 2'. Longitude 38° 43' E. Altitude 2440 metres.

DATE		Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1898 *a*)	..	8	15	105	73	41	121	347	308	148	4	9	0	1179
„ *c*)	..	..	..	..	..	..	..	356	273	154	31	11	0	..
1899 *c*)	..	0	11	..	..	..	..	..	..	..	..	..	..	..
1900 *c*)	..	..	..	..	..	..	[108]	283	328	194	0	13	5	[931]
1901 *b*)	..	..	54	133	111	35	212	276	240	139	15	0	13	[1228]
„ *c*)	..	16	53	114	88	38	232	278	261	118	27	0	16	1241
„ *d*)	..	..	..	..	..	..	..	..	..	..	..	0	9	..
1902 *b*)	..	1	75	63	76	33	188	236	291	184	..	..	..	[1147]
„ *c*)	..	2	88	46	80	32	[156]	..	..	..	0	11	1	..
„ *d*)	..	0	65	38	111	61	..	..	..	..	..	..	..	..
1903 *b*)	..	..	..	..	..	..	..	262	244	225	10	0	0	..
„ *c*)	..	29	..	72	..	..	..	..	309	..	21	0	17	..
„ *d*)	..	..	..	..	..	..	191	276	248	223	28	0	18	[984]
1904 *b*)	..	0	49	171	56	66	120	375	..	..	..	..	..	..
„ *c*)	..	0	43	110	58	51	129	324	201	147	36	0	0	1099
„ *d*)	..	0	20	126	..	..	..	..	..	..	..	..	..	..
1905 *b*)	..	..	..	..	..	..	..	..	..	..	1	45	0	..
„ *c*)	..	5	7	48	..	..	..	..	..	..	..	..	..	..

a) = Ann. Bur. Meteor. Cent., Paris. *c*) = Nicolas Cent. Obsy.
b) = Dr. Wakeman. *d*) = Italian.

[1] Nicolas Central Observatory, St. Petersburg.
[2] Furnished by the Director of the Meteorological Observatory at Rome.
[3] Made by Dr. Wakeman of the British Agency.
[4] "Annales du Bureau Meteor. Cent." Paris.

MEAN VALUES DERIVED FROM THE ABOVE OBSERVATIONS.

DATE	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1898.. ..	8	15	105	73	41	121	352	290	151	18	10	0	1184
1899.. ..	0	11	..	..	..	..	..	..	..	..	..	..	[11]
1900.. ..	..	..	..	..	..	108]	283	328	194	0	13	5	[931]
1901.. ..	16	54	124	100	36	222	277	250	128	21	0	13	1241
1902.. ..	1	76	49	89	42	172	236	291	184	0	11	1	1152
1903.. ..	29	..	72	..	..	191	269	267	224	20	0	12	[1084]
1904.. ..	0	37	136	57	58	124	350	201	147	36	0	0	1146
1905.. ..	5	7	48	..	..	..	..	..	..	1	45	0	[106]
Mean. ..	8	33	89	80	44	156	294	271	171	14	11	4	1175

Addis Alem.—Latitude 9° 0′. Altitude 2348 metres.

DATE	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1902*d*) ..	..	..	..	..	..	142	205	167	130	17	9	40	..
,, *c*) ..	..	..	..	..	..	..	174	166	140	..	..	..	..
1903*d*) ..	33	25	94	88	268	..	..	..	..	..	..	..	..

RAINY DAYS.

Ankober.—Latitude 9° 35′ N. Altitude 2500 metres.

DATE	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1841.. ..	..	..	..	..	..	..	..	26	13	4	4	0	..
1842.. ..	0	7	4	14	4	8	28	..	..	..	..	..	..

Magdala.—Latitude 11° 23′ N. Altitude 2760 metres.

DATE	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1866.. ..	..	..	..	..	..	..	23	27	7	2	0	1	..
1867.. ..	11	1	10	2	3	5	22	24	9	2	0	0	..
1868.. ..	2	8	2	3	..	..	..	..	..	..	..	..	..

MONTHLY RAINFALL IN MILLIMETRES.

Gondar.—Latitude 12° 36′ N. Altitude 1904 metres.

DATE	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1770.. ..	..	..	..	..	69	109	256	395	72	0	0	0	[901]
1771.. ..	..	..	..	..	66	135	310	324	129	..	..	..	[964]
1838.. ..	..	..	..	..	..	..	304	398	108	92	..	..	[902]

Intetshau.—Latitude 14° 20′ N.

DATE	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1841.. ..	0	0	0	37	68	74	302	177	126	0	0	0	784

Adua.—Latitude 14° 15′ Altitude 1910 metres.

DATE	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1842.. ..	..	..	..	..	..	51	236	289	209	65	..	..	850

Addi Ugri.—Latitude 14° 53′ N. Longitude 38° 49′ E. Altitude 2022 metres.

DATE	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1894. ..	..	..	..	..	130	50	165	258	68	0	6	1	[678]
1895. ..	0	11	13	25	11	81	159	140	0	0	0	8	448
1899. ..	0	0	0	26	37	44	119	62	15	8	5	8	324
1900. ..	0	0	41	5	42	93	208	147	64	0	0	25	625
1901. ..	1	0	7	32	10	34	123	290	37	0	10	0	544
1902. ..	0	25	16	27	30	76	182	191	34	35	34	0	650
1903. ..	0	1	18	6	4	60	92	226	45	2	2	0	450
1904. ..	0	0	1	..	..	101	138	111	13	7	0	0	[371]
1905. ..	0	15	9	18	70	58	224	186	56	39	24	0	699
Mean ..	0	6	13	20	42	66	157	179	37	10	9	5	544

Asmara.—Latitude 15° 20′ N. Altitude 2372 metres.

DATE	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1894. ..	..	..	..	..	98	31	100	46	34	3	29	..	..
1895. ..	..	..	..	30	..	..	..	..	..	..	..	..	..
1901. ..	..	..	..	..	..	..	..	..	..	..	..	9	..
1904. ..	..	..	28	10	36	32	136	110	10	56	..	..	..
1905. ..	1	3	3	26	..	93	99	117	25	..	..	..	..
Mean ..	1	3	16	22	67	52	112	84	23	30	29	9	448

Chenafena.—Latitude 14° 48′ N. Longitude 39° 1′ E. Altitude 1631 metres.

DATE	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1903. ..	..	..	..	1	95	19	111	209	36	8	0	0	[479]
1904. ..	..	..	..	10	13	47	149	90	3	..	..	..	[307]
1905. ..	..	..	..	..	..	..	73	136	72	..	..	..	..
Mean ..	..	..	..	6	54	33	111	145	37	8	0	0	[304]

Halai.—Latitude 15° 0′ N. Altitude 2565 metres.

DATE	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1894. ..	..	..	..	..	63	15	114	154	4	2	6	..	[358]

Keren.—Latitude 15° 46′. Altitude 1460 metres.

DATE	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1890 ..	..	..	..	..	..	..	..	..	35	2	0	0	[37]
1891 ..	0	0	1	21	13	34	57	174	66	0	4	0	370
1892 ..	0	0	0	4	8	14	104	234	89	3	0	0	456
1893 ..	1	0	9	2	21	..	47	162	103	..	0	0	[345]
1894 ..	0	15	0	1	6	172	119	..	168	0	0	0	[481]
1895 ..	..	..	0	26	78	206	206	630	11	5	35	0	1200
1896 ..	0	0	0	2	..	..	..	..	..	..	..	..	..
Mean..	0	3	2	9	25	106	107	300	79	2	6	0	639

In 1861 from July 23 to September 22, 464 mm. of rain fell.[1]

1 V. Heuglin "Reise in Abessinien," Gera, 1874, p. 104.

Suakin.—Latitude 19° 5′ N. Longitude 37° 20′ E. Altitude 5 metres.

Date	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1890 ..	..	2	0	1	0	0	2	25	0	30	40	66	[166]
1891 ..	3	0	2	3	0	0	0	0	0	5	112	18	143
1892 ..	22	6	0	0	0	0	17	6	0	6	6	29	92
1893 ..	127	2	0	0	0	3	0	0	0	16	31	16	195
1894 ..	36	1	0	0	0	0	15	0	0	0	29	25	106
1895 ..	14	16	0	13	0	0	0	0	0	0	327	..	[370]
1896 ..	16	4	0	0	0	0	6	43	0	269	274	4	616
1897 ..	15	0	0	0	0	0	0	9	0	0	14	20	58
1898 ..	32	0	0	0	0	0	0	0	0	6	178	234	450
1899 ..	8	0	0	0	..	0	0	0	0	0	60	105	[173]
1900 ..	37	0	0	0	0	0	0	0	0	0	0	0	37
1901 ..	5	88	5	0	0	0	0	0	0	80	16	111	305
1902 ..	0	24	0	0	0	3	9	0	0	122	155	52	365
1903 ..	49	10	0	0	12	0	0	3	0	0	32	58	164
1904 ..	8	0	0	0	0	0	0	0	0	87	60	19	174
1905 ..	17	3	0	0	0	0	0	0	7	0	122	0	149
Mean..	[26]	10	0	1	[1]	0	3	5	0	39	97	48	229

Roseires.—Latitude 12° 00′ N. Altitude 450 metres.

Date	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1900	0	0	0	0	0	0	202	184	205	15	10	0	616
1904	..	..	..	0	37	52	290	222	104	1	0	0	706
1905	0	0	0	0	65	179	207	160	134	66	24	0	835
Mean..	0	0	0	0	34	77	233	189	148	27	11	0	719

Wad Medani.—Latitude 14° 24′. Altitude 410 metres.

Date	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1902	..	..	0	0	6	53	135	78	41	2	0	0	315
1903	0	0	0	0	2	4	12	9	5	0	0	0	32
1904	0	0	0	0	40	0	85	67	77	4	12	0	285
1905	0	0	0	0	54	99	162	291	120	0	0	0	726
Mean..	0	0	0	0	34	52	131	135	81	2	4	0	439

It has been maintained[1] that we have no idea how heavy the Abyssinian rainfall may be in year when it furnishes a high Nile flood.

[1] Willcocks, Geog. Jour. December, 1905, p. 688.

But though actual measured rainfall in such a year is not available we know from observations of the river levels at Aswan and discharges at Khartoum, that the volume of the Nile flood varies from about 1·26 to 0·63 of a mean flood. Since this is the run-off of the Abyssinian tableland, the range of the rainfall on it will be somewhat less since the ratio of run-off to rainfall is less in a very dry year and greater in a very wet year than in one of average precipitation.

The mean amount of rain is shown below though the totals cannot be considered as accurate determinations, since only 2 or 3 years observations at most stations are available; moreover there are no observations of the amount which falls any point south of Addis Abbaba and the Abai except Nasser and Gambela. Seeing that here the rainy season begins earlier and ends later than further to the north, perhaps it may be fairly assumed that the rainfall of the southern part of the tableland may reach 1500-1800 millimetres per annum.

MEAN MONTHLY RAINFALL IN MILLIMETRES.

	Years	Jan.	Feb.	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Eastern Sudan Plains.														
Khartoum	7	0	0	0	0	4	25	24	**34**	10	10	0	0	107
Kassala	6	0	0	0	2	7	24	69	**108**	66	17	1	0	296
Khashm el Girba ..	3	..	..	..	..	..	18	102	**105**	59	20	..	..	[304]
Gedaref	2 6/12	0	0	6	0	37	86	**177**	161	107	10	15	0	599
Gallabat	2 6/12	0	0	0	1	46	150	191	**247**	143	52	6	0	836
Wad Medani	4	0	0	0	0	34	52	131	**135**	81	2	4	0	439
Roseires	2 3/12	0	0	0	0	34	77	**233**	189	148	27	11	0	719
Abyssinia Tableland.														
Keren	5 3/12	0	3	2	9	25	106	107	***300**	79	2	6	0	639
Asmara	1 4/12	2	3	16	18	36	62	**117**	114	18	56	..	..	442
Chenafena	1 6/12	..	..	..	6	54	33	111	**145**	37	8	0	0	[394]
Halai	1	..	..	..	..	63	15	114	**154**	4	2	6	0	[358]
Addi Ugri	8 6/12	0	6	13	22	42	66	157	**179**	37	10	9	5	546
Adua	1	..	..	..	..	..	51	236	**289**	209	65	..	..	[850]
Intetshau	1	..	..	..	37	68	74	**302**	177	126	0	0	0	[784]
Gondar	1 10/12	0	0	0	0	67	122	290	**372**	103	46	14	0	1014
Addis Abbaba	6 7/12	9	37	87	79	86	160	**290**	271	171	13	11	4	1218

* Probably too high a mean value due to 630 mm. having fallen in Aug. 1895.

While on the plateau round Addis Abbaba the mean annual rainfall amounts to 1300 millimetres, to the north of the Abai in Gojam, and on the Chok plateau it must rise to 1500 millimetres; on the Gondar plain up to the Takazze it is 1000 millimetres, and more on the Simien mountains, and to the north of this 750 millimetres until the basin of the Mareb is entered for which about 500 millimetres may be estimated.

On the Sudan plains the heaviest rainfall is at those places nearest to the hills where it amounts to 600-700 millimetres falling to 400 and 300 millimetres for the more western or northerly stations.

If now we take the most reliable stations for the summer rainfall, while admitting that they furnish very inadequate data, it is possible however to gain a general idea of the distribution of the rainfall from April to September; from this an estimate can be formed of the probable loss of water or diminution of the flood volume by the dry intervals which frequently occur, and are shown by a rapid fall in the river gauges.

MEAN RAINFALL IN THE RAINY SEASON IN MILLIMETRES.

	April	May	June	July	Aug.	Sept.
Keren	9	25	107	106	300	78
Asmara	18	36	62	117	114	18
Halai	..	63	15	114	154	4
Addi Ugri	22	42	66	157	179	37
Intetshau	37	68	74	302	177	126
Gondar	0	67	122	290	372	103
Addis Abbaba	79	83	160	290	271	171
Roseires	0	51	116	233	189	148
Mean	26	55	90	201	220	86
Percentage..	4	8	13	30	32	13

Thus a deficiency equal to the average rainfall of ten days in August would reduce the amount of water flowing to the Nile by about 11 % of the summer flood while same dry period in June would only affect it by about 4%. These shortages will be shown very markedly at the upper river gauges while further down stream they will merely flatten the curve of the year's gauge readings.

A maximum flood is about double the volume of a minimum flood and a somewhat similar relation must hold between the rainfalls of such years; but at present the data are too scanty to enable us to trace such a relation satisfactorily. In the following tables it will be seen that there is little difference in the rainfall measured at Addis Abbaba between 1901 a rather low flood year, and 1902 which was an extremely bad year. Addi Ugri shows the variation better since the fall in 1899 was particularly small and that of 1894 very large; Keren does not show the variation well and at Ginda the winter rains are much heavier than the summer rains. Suakin shows it also to some extent since only in years of good rainfall does any reach that place in the summer months.

Thus from the meagre rainfall data at our disposal it is impossible to trace satisfactorily the effect in the floods of the corresponding years since the stations having records are so few.

Lake Tsana.—During the last 130 years Lake Tsana has been visited by several travellers, and from their descriptions a fairly complete account of the lake and its shores can be compiled.

Bruce [1] describes the northern, eastern and southern shores of the lake as well as the source of the Abai river and the cataract of Alata.

Rüppell[2] left Gondar in February 1833 and travelled along the eastern shore to the Abai river where he visited the Alata or Tis Esat cataract, and in March returned by the same road to Gondar.

In January 1838 Combes and Tamisier [3] crossed the Abai at the bridge of Alata and a few days later travelled from Debra Tabor to Gondar thus skirting the NE. corner of the lake.

Plowden [4] between 1843 and 1847 visited at various times the southern portion of the lake and also the river Abai.

Dr. C. T. Beke [5] visited in 1842-3 the sources of the river Abai as well as the two bridges which span it below the lake.

Von Heuglin [6] in 1853 left Metemma (Gallabat) in January and reached the north shore of the lake in 10 days; thence he went northwards to Gondar and to Entshakab in the Simien province, returning later to the lake. After camping on its northern shore for some days, he followed it westward as far as the southern limits of the district of Dagossa, where he turned west and returned to Metemma by the Anaho road.

In February 1862 [7] von Heuglin was again at Gondar, and leaving it travelled to Debra Tabor round the north-east corner of the lake; in May he returned to the northern shore by the same road, and thence to Gallabat. In September Cameron and Baron A. d'Ablaing travelled from Gondar along the western shore to Debra Mai in north Gojam.

In 1865 Blanc [8] went in December with H. Rassam [9] from Metemma (Gallabat) to the Damot district of southern Gojam, to obtain the

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1 Travels to discover the sources of the Nile in 1768-73. Vol. V., p. 104 and p. 307.
2 "Reise in Abessinien," Frankfurt, 1840.
3 "Voyage en Abyssinie," Paris, 1838.
4 Abyssinia and the Galla Country, London, 1868.
5 Journal. R. Geog. Soc. vols. XII, XIII, XIV.
6 "Reise nach Abessinien," Gotha, 1857.
7 "Reise nach Abessinien," Gera, 1874.
8 Narrative of Captivity in Abyssinia, also Jour. R. Geog. Soc. 1869.
9 Narrative of the British Mission to Theodore, London, 1869.

release of the Europeans imprisoned by King Theodore. He reached Goja on the west shore of the lake by the usual road, then after following the shore southwards for about half its length, turned inland; subsequently he visited the source of the river Abai and also the southern part of the lake.

In 1881 G. Rohlfs [1] reached Debra Tabor, 50 kilometres east of the lake in February, and then travelled to Gondar having skirted the north-eastern angle of the lake. Stecker, who was accompanying Rohlfs, went to Koratsa and the southern extremity of the lake; leaving this he visited the river Abai where it leaves the lake and made an almost complete circuit of lake Tsana. Having travelled round the east, north and western shores, he was stopped at the mouth of the Abai where it enters the lake, and was obliged to return to Debra Tabor passing round by the north. A few days later he returned to Koratsa and examined the peninsula of Zegi, between the incoming and outflowing Abai streams. In the two and a half months so spent he made a careful survey of the lake and took a large number of observations for latitude, azimuth, and altitude, besides meteorological observations. Unfortunately only a part of these ever reached Germany and these were published, together with a map on the scale of $\frac{1}{200000}$. [2]

A. d'Abbadie about 1840-45 took meteorological observations at various places in Abyssinia, and also visited the Abai river and its source as well as Lake Tsana.

Lake Tsana [3] is approximately rectangular in shape, being about 60 kilometres from east to west and 50 kilometres from north to south, while a small bay about 20 kilometres by 10 on the southern side contains the outflow of the lake, the river Abai.

It lies in a comparatively shallow depression about 1755 metres above sea level, from which on all sides the country rises gently to 2000 metres and then more rapidly to 2500 metres and in places to 3000 metres in the heights which enclose the Tsana basin. The hill masses and plateaux which limit the basin are:—

On the north, the plateau and hills of Wogera district behind Gondar, rising to 3000 metres.

On the east, the narrow ridge of the hills of Begemeder district rising to 3000 metres and separating the Tsana basin from that of the

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[1] "Meine Mission nach Abessinien."

[2] Mitt. d. Afrik. Gesell. in Deutschland, III. i.

[3] For the most recent and complete description, see Dupuis in A Report on the Basin of the Upper Nile Cairo, 1904.

Takazze river. This ridge bends to the south and culminates in Mount Guna (4200 metres), the western spurs of which form the water parting between the lake and the Abai river. South of the lake, the northern spurs of the Chok plateau, which rises to over 4000 metres, divide the drainage of the Abai river from that of the upper Abai which falls into the lake; the western spurs divide the upper Abai from the Bir, the Tattam, the Durra and other large streams which flow southwards to join the Abai south of Gojam. On the west, a ridge of hills, unexplored for the most part, divides the lake basin from the headwaters of the Dinder, the Rahad and the Atbara.

The approximate area of the catchment basin is 17,000 square kilometres, of which the area of the lake is about 3000. Its perimeter is about 260 kilometres.

The depth of the southern half of the lake varies from 30 to 70 metres, and the northern half is believed to be rather deeper; the yearly range of the water level is from 1·25 to 1·75 metres.

The altitude of the water-surface, 1755 metres above sea level, has been deduced from a series of barometric observations taken by Stecker and Rohlfs in 1881.

The supply of the lake is mainly furnished by the following streams:—

Upper Abai	On the south.
Derma	On the north.
Magetsh...	On the north.
Gumara	On the north.
Reb	On the east
Gumara (a different one)	On the east
Gelda	On the east

The only effluent is the Abai at the southern extremity of the lake.

The Dembea district, which contains the ancient capital, Gondar, extends from the Wogera plateau, north of that town to the shores of the lake. It is on the whole an undulating expanse of country sloping gradually to the lake, very fertile, and is usually described as one of the richest provinces of Amhara. It is watered by numerous streams flowing from the Walli Dabba range on the west, and by the three rivers, the Dirma, which rises in the hills to the N.W. of Gondar, the Magetsh, with its sources in the hills immediately north of Gondar, and the Gumara which rises to the N.E. of the lake and forms the boundary between Dembea and Begemeder. The southern portion of the district is quite level with the exception of the hilly promontory of Gorgora (2,130 metres) and is described by von Heuglin as being

used for pasturage only, except near the town of Chelga on the west, Munsero on the east, and near Gondar where the land is cultivated.

At Chelga are the beds of lignite mentioned by von Heuglin and others; these have recently been examined by Barron but they do not seem to be of much economic importance.

The promontory of Gorgora[1] is composed of crystalline rocks (schists) on which lie sandstones similar to those which occur at Chelga (to the N.W.); clear remains of a large lava flow which could be traced to the lake as well as ancient eruptive cones are also mentioned.

Begemeder is a large district which seems to occupy about 40 kilometres of the eastern shore of the lake between the (northern) Gumara river and the river Reb. To the east it extends under the Begemeder hill range up the valley drained by the river Reb as far as Debra Tabor a small district at the foot of the Guna mountain.

At the northern end of the district the spurs of the hills come close to the shore of the lake, and masses of ancient volcanic rocks with the remains of former craters are often seen. Several villages lie here near the lake in small fertile valleys.

The streams which here flow into the lake are about 6 metres wide and 0·3 metre deep at the fords. The principal road from Gondar to the east and south-east of Abyssinia leads up the valley of the Reb[2] to Debra Tabor. This valley is fertile and equable in climate, and the Reb, which has cut a deep channel in the rich alluvial soil, flows slowly to the lake throughout the year between almost vertical banks. The low land near the lake through which the Reb and (southern) Gumara rivers flow is flooded in the rainy season. Dupuis found the volume discharged by them in the dry season to be very small.

Fogara district includes the area south of the Reb which is drained by the (southern) Gumara river.[3] Close to the lake the land is low and flat, and is flooded annually. Higher up the Gumara the country rises fairly rapidly and the river flows between high volcanic cliffs of porphyry and trachyte. Hot springs exist at Wansage 20 kilometres up the valley, and are much frequented.

Dera district of which the principal town is Koratsa, the largest on the lake, lies south of the Gumara, and both this district and the next Afferavanet are hilly, the central hill mass rising to over 2000 metres.

Immediately south of Koratsa the river Gelda 3 metres wide 2 metres deep flows steadily to lake. In rains it rises to 10 metres deep (Rüppell).

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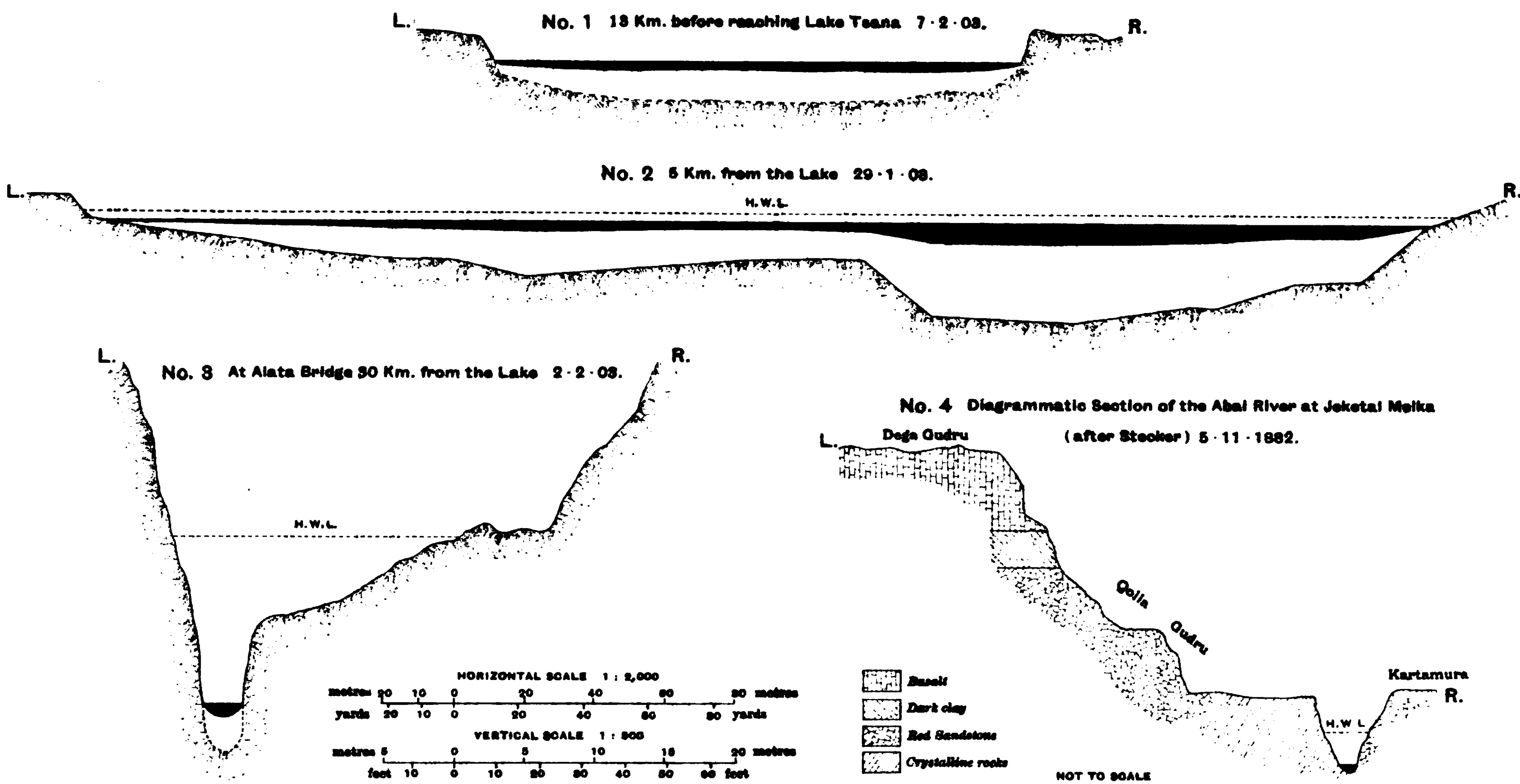
[1] Stecker loc. cit.

[2] The Reb where the Koratsa road crosses it was 50ft. wide and 3½ft. deep in February (Rüppell).

[3] The Gumara where the Koratsa road crosses it was 50 ft. wide and 4½ ft. deep in February (Rüppell).

SECTIONS OF THE ABAI RIVER



SURVEY DEPT.

[illegible] THE ABA [illegible]

No. 1 [illegible] before reaching Lake [illegible]

No. 2 [illegible] from the Lake [illegible]

[illegible] from the Lake [illegible]

No. 4 [illegible] from the Section of the [illegible]

[illegible]

Leaving the description of the Abai itself till later, the next district is Mietsha which extends to the upper Abai. This part has been but little visited and accounts of it are meagre. It is said to be fertile, the lower parts near the valley of the upper Abai being flooded in the rainy season.

Abaidar through which the Upper Abai flows towards the lake is fertile and wooded, but subject to floods in the lower part. Since the sources of the Abai lie on the flanks of the Gojam plateau this river rises earlier than the others which flow into the lake, as in Gojam the rains begin before they do in Ambara.

Wendige, Alefa, and Dagossa, the western districts appear to be hilly rising rapidly westwards up to the Walli Dabba and Atshefer mountain ranges which separate Abyssinia from the Sudan. The hills come down to the lake at many points, and agriculture is confined to the valleys between the spurs. In the rainy season these are flooded and a road further inland has to be followed.

A road from Famaka, by the Kienien Hills, and another from Dunkur are said to lead from these western districts to the Sudan but they have not yet been mapped. There are few villages in this part and the inhabitants seem always to have had a bad character for robbery and violence. The most frequented road to the Sudan is that from N.W. corner of the lake to Wohne and Gallabat by the valley of the Bulweha River; another longer road leads from Alefa district to Anaho, Ambo and so to Metemma. [1]

The Abai River.—Tbe Abai river consists of two portions. The upper reach is approximately 200-250 kilometres long from its source at Mount Giesh at the western end of the Chok plateau near Sakala, to the point at which it falls into the lake. The source has been described by Bruce, d'Abbadie, Plowden, and Beke, as well as by the earlier Portugese travellers in the country and at a short distance down stream the Abai is said to be 4 metres wide, 0·20 metre deep and flowing 6 kilometres an hour. At 15 kilometres from the source Blanc found it in January 10 metres wide, 0·6 to 0·9 metre deep and having banks 3 metres high.

The land where it flows into the lake is flooded in the rains and this may be the explanation of Bruce's estimated width of 2000 ft. where it enters the lake. Stecker gives the channel at its mouth in May 1881 as 10 metres wide.

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[1] Von Heuglin, 1852.

Dupuis[1] visited it in February 1903 and crossing it at a point several kilometres above its junction with the lake found it to be a fine-looking stream with a well-defined section 80 metres wide and not less than 4 metres deep. The valley was about 1500 metres wide and was said to be flooded for three months in the rainy season. He estimated the discharge as about 9 cubic metres per second.

The flow of the water from the upper Abai is said to be plainly visible between Dek island and the promontory of Zegi. The second portion of Abai leaves the lake at its southern extremity and flows in a south-easterly direction. The width of the Abai where it leaves the lake is given by Stecker as 100 metres wide and 8 metres deep in the centre, but no velocity is given; this was in April.

A. d'Abbadie quoted by Klöden gives it as 200 metres wide 3 metres deep, and a velocity of 800 metres per hour or 0·222 metre per second.

From this point the river flows between somewhat hilly shores, while several small islands occur at intervals. At Woreb 6 kilometres from the actual junction with the lake, these so increase as to be described as forming rapids; soon after this the river bed gradually narrows until the river rushes through the narrow cleft in the rock just below the Falls and Cataract of Tis Esat or Alata. This has been visited and described by Bruce, Rüppell, Beke and d'Abbadie. The bridge of Alata is ¾ hours march from where the river of that name falls into the Abai. The bridge which spans the river at a short distance below the falls was constructed by the Portugese and is built of basalt with the arches filled in with small dressed sandstone blocks; it consists of one arch which spans the river, and seven or eight other arches on the western or Mietsha side. The main arch is 25 ft. in span and is built on and into the solid rock on either side. The roadway is 15 feet wide including the parapet which was originally 2 feet high. The river runs with great violence through a deep gorge or fissure more than 60 feet deep and often not more than 12 to 15 feet wide, in an unbroken line of foaming cascades. In the rainy season this whole gorge is not only filled with water, but the river overflows to a considerable extent the right bank which is covered with great, rounded boulders of basalt derived from the hills which lie directly on the banks on either side and are formed of volcanic rock masses partly overgrown with trees.[2] About 30 metres up-stream of the falls the upper edges of the gorge approach till they are only 3 metres apart.

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[1] Loc. cit., p. 13.
[2] Rüppell loc. cit.

For a quarter of an hour's walk up-stream this series of falls and rapids continues up to the waterfall itself, where the river plunges down 12 metres in a cloud of mist and spray. Bruce says the river at the falls was half a mile wide when swollen by rains, but this seems excessive.

Above the fall the river is described as "gliding through a fine grassy plain between a line of dark foliage on either bank, its smooth surface being disturbed by only a few ripples, for so appear in the distance some slight rapids." A ridge of rock crosses it at the head of the fall and over this it plunges down into the gorge below.

About 50 kilometres down-stream of this bridge of Alata is another bridge now broken, called the Andabit bridge or sometimes the Upper bridge while that of Alata is called the Lower.

It is built of rough stones and lime, while the arches are turned in large flat bricks. The bridge formerly carried a roadway 4 metres wide and had no parapet. It has nine arches of which one 18 metres wide spans the river, of the rest five are on the east or Begemeder side, and three on the west or Gojam side. The fall from the lake to this point is said to be 415 metres, or on the average 6 metres per kilometre including the falls.

D'Abbadie's data for the river Abai, 200 metres wide, 3 metres deep, velocity 800 metres per hour, give a discharge in the dry season of 135 cubic metres per second which seems too large. Dupuis[1] has described the course of the Abai from the lake to the Tis Esat-Cataract in detail and by measurement found the discharge from the lake to be 42 cubic metres per second on January 31, 1903.

Rüppell states that the gorge runs full in the middle of the rainy season and Dupuis' section shows the same, so a large volume must be discharged at this season.

Though some travellers have considered the Didessa to be the true upper course of the Blue Nile, and the Abai to be a tributary only[2] it is to-day generally agreed that the source of the Blue Nile is where the Abai takes its rise. Data concerning the width, depth, and velocity of these rivers are scarce but a few measurements are given by travellers who have traversed the country.

Rochet[3] at the end of October 1839 found Abai just above its junction with the Muger river to be 3 to 4 metres deep and 60 to 70 metres wide.

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[1] In A Report the Basin of the Upper Nile, Cairo, 1904, p. 13 and Plan XII*a*, 3.
[2] D'Abbadie B.S.G. Oct. 1860, p. 291.
[3] "Voyage dans le pays d'Adel et le Royaume de Schoa." Paris 1841, p. 173.

At the end of May 1842 Beke[1] visited a crossing place on the Abai, Melka Furi, where he found the river 50 metres wide, and 1·5 metres deep. He gives the latitude of this point as 9° 54′ 40″ N. Here the valley sides descend in two steps of which the upper is nearly 200 metres in height. At Melka Kuki further down-stream the river was about 70 metres wide.

Cecchi[2] found the Abai a river 300 metres wide with a rocky bed, and flowing as a muddy rapid torrent in September 1880 just below the point where the Guder joins it. At this point the river was flowing at an altitude of 990 metres in the bottom of a deep trough cut in a plateau 2480 metres above sea level the left bank rising to this level in a distance of 10·7 kilometres and the right bank in 40 kilometres the top of the valley being 50 kilometres from side to side.[3]

An instructive section of the Abai valley is given by Stecker,[4] who crossed it at the ford called Jeketal Melka (908 metres) about 12 kilometres down-stream of the Guder river. The south side of the valley consists of the high plateau (Dega) capped by a considerable thickness of basalt, under which is a bed of bright-coloured clays which in their turn overlie a considerable thickness of red sandstone; below this are the clayslates and crystalline schists of an older series. On the north side is the sandstone down to the river level so that the Abai seems here to have cut out its valley along a line of fault. The river on May 11. 1882 was 2 metres deep and 12 metres wide and flowing rapidly but in flood it is 15 metres deep and about 80 metres wide. Two terraces one on the crystalline schists, and the other halfway up the sandstone are well marked.

Lower down (865 metres above sea-level) d'Abbadie[5] on April 9, 1844 found it 55 metres wide 1·3 metres deep and flowing at the rate of from 5 to 6 kilometres an hour, 1·39 to 1·66 metres per second; this would be equivalent to a discharge of about 100 cubic metres per second.

The tributaries of the Abai and Blue Nile are very numerous, and only the more important ones can be mentioned here. On the left bank the first of any size is the Bashilo river which rises near the eastern escarpment to the south of Magdala at an altitude of about 3500 metres, at the foot of Kollo mountain which reaches an altitude of 4200

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1 Jour. R. Geog. Soc. Vol. XII

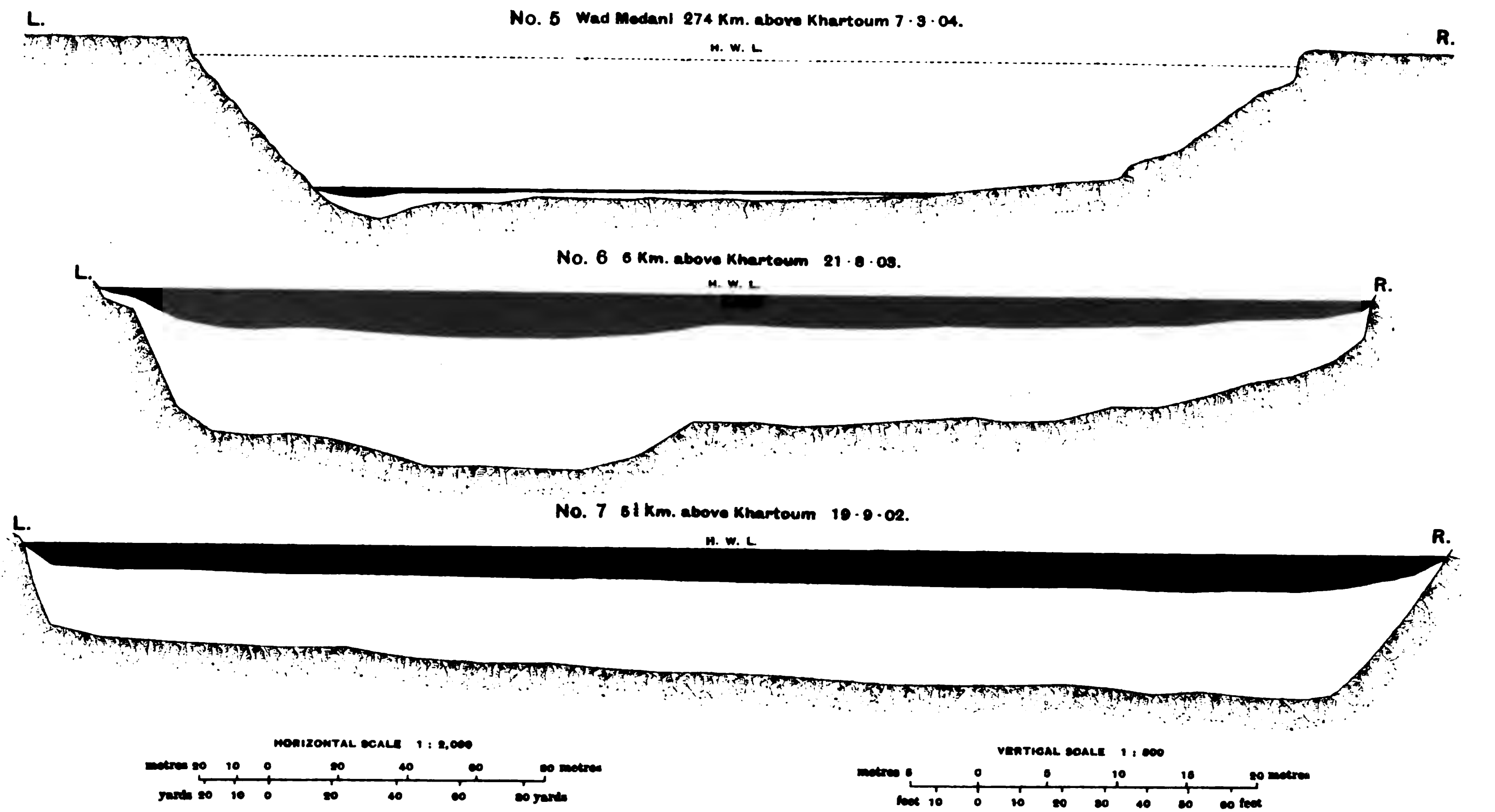
2 Cecchi. "Da Zeila alle frontiere del Caffa." Rome, 1887, Vol. II, p. 367.

3 Cecchi. Vol. III, Plate 8.

4 Pet. Mitt. 1891, p. 233. (See Plate XXIIa. 4 reproduced with the kind permission of the Editor of Petermanns Geographische Mitteilungen.)

5 "Observations relatives à la physique du Globe," p. 11, Paris. 1873.

SECTIONS OF THE BLUE NILE



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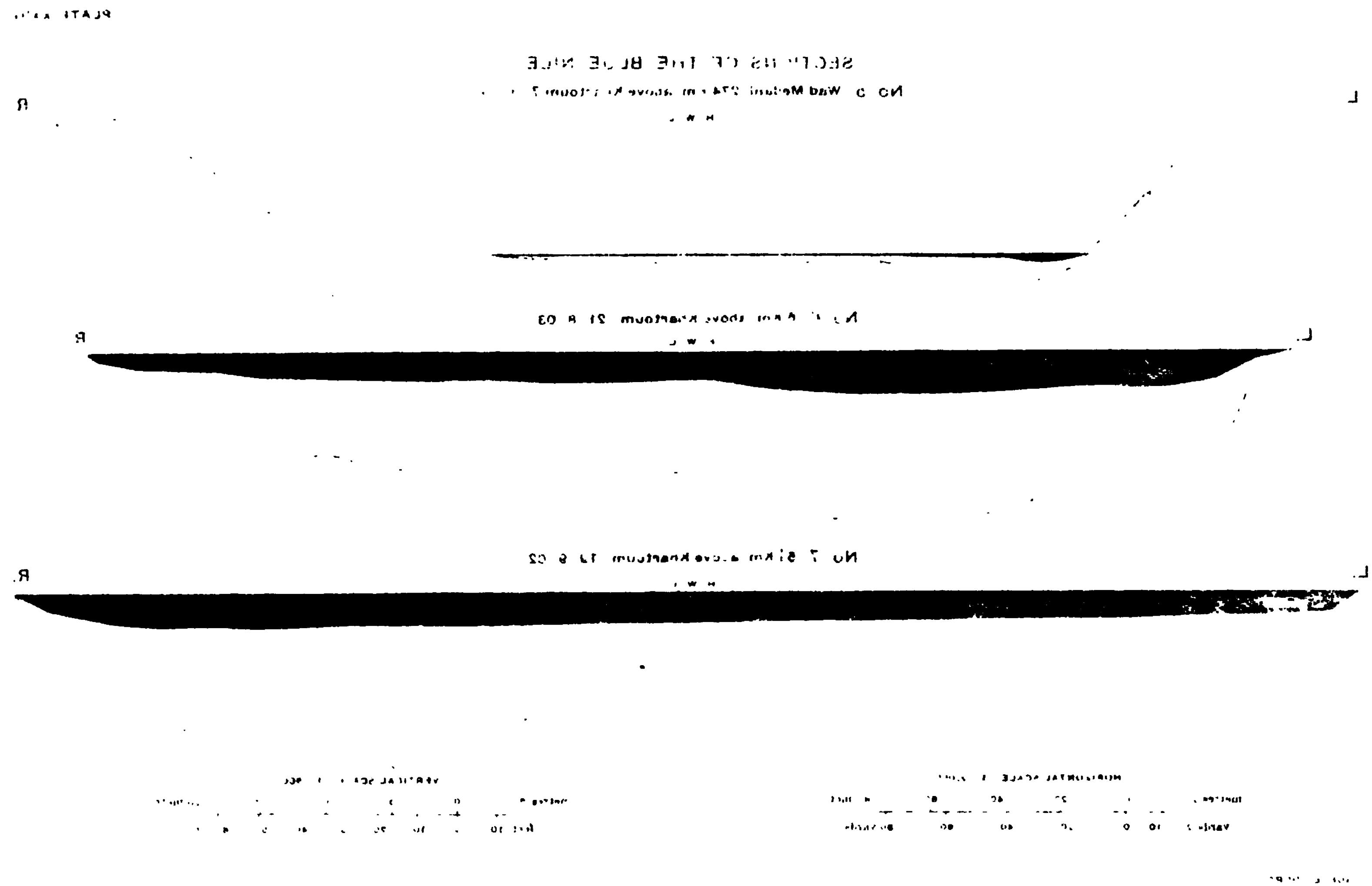

SECTIONS OF THE BLUE NILE
No 7 51 Km above Khartoum 12 6 02

metres; from here it flows northwards and then south-westwards to join the Abai or Blue Nile. Von Heuglin[1] crossed this river and its tributary the Jidda in March 1862. He describes the valley of the latter as being about 750 metres deep, cut down in two almost perpendicular steps through the basalt which is markedly columnar; at the foot of the second was the river bed 150 metres wide, in which three branches of the stream then flowed about half a metre deep. The bed of the Bashilo, at the botton of a similar ravine, was 100 metres wide in which a stream 25 metres wide and 0·7 metre deep was flowing rapidly.[2]

The next important stream is the Jamma, which rises near Ankober and drains a large part of Shoa; from where it joins the Abai, the united streams turn south-west, having at this point a width of 60 to 70 metres and a depth of 3 or 4 metres, according to Rochet;[3] the Muger rises to the north of Addis Abbaba and joins the Abai a little south of lat. 10° N.; the Guder rises on the north side of the Rogge mountains, which divide its basin from that of the Omo and the Hawash. After these comes the Didessa, which is the most important tributary of the Blue Nile. Rising somewhat south of lat. 8° N. and near the headwaters of the Baro, it flows northwards to the Abai, which it meets just south of lat. 10° N., and in about long. 35° 40′ E.[4]

Michel[5] crossed it at two points high up, one 59 kilometres below the ford opposite Mount Deka, to the west of Bilo, and the other at the ford. On June 12, 1897, it was 110 metres wide, of which 40 metres was the main channel having a depth of 3·35 metres, while the depth outside the channel was 1 metre. The velocity was 1·30 metre per second, so that the discharge was about 110 cubic metres per second. It had commenced to rise on May 25, and fell from October 10; the water was turbid and red in colour.

At the second place a more detailed section was taken on September 13, 1897.

	Metres.	Metres.	Metres	Metres.	Metres.
Distance from left bank	5	25	60	95	105
Depth	2·80	3·55	4·20	4·0	3·05

This gives a sectional area of 392 square metres, and this with a mean velocity of 1·80 metre per second corresponds to a discharge of about

1 "Reise nach Abessinien." Gera, 1874, pp. 318, 332.
2 The Jidda is dry before the rains, Pet Mitt., 1868, p. 315.
3 Von Klöden, "Stromsystem des oberen Nil," p. 202. Berlin, 1856.
4 Weld Blundell, Geog. Jour., March, 1900. Hughes Le Roux, "Menelik et nous." Paris, 1901.
5 "Vers Fachoda," p. 557. Paris, 1900.

700 cubic metres per second. At this season its valley was flooded to a depth of 60 centimetres. At the beginning of April, 1898, the Didessa at this same place was only 45 metres wide and 0·45 metre deep.

These measurements were all taken before the Anjur joins it, so that they must be below the total amount which it carries to the Abai and its volume in flood may probably be taken as about 1000 cubic metres per second. In its early rise, long flood period, and late fall, the Didessa is, in its regimen, very like the Sobat, near the headwaters of which it rises, though it has no wide flooded plains, like those of the Pibor, to delay its fall.

As this part of the course of the Blue Nile has been little visited, I give a description of it from the Didessa junction to Famaka, for which I am indebted to Mr. A. Hay, who was recently for some time in this part of the country.

"Just about 2 miles above its junction with the Didessa river, the Blue Nile emerges from a high gorge in a range of mountains. At the end of the hills there is a shallow, rocky, gravel-bottomed rapid, and here the river, hitherto running almost due north, makes a sharp bend to due west. At the end of this stretch, which is about a mile long, the Didessa joins the Abai and appears to come in on a course similar to that which the Blue Nile now assumes after another sharp bend to north-west. The Didessa is very rocky, and full of rapids just above the confluence. The Blue Nile now travels about 10° west of north to due west. At the top of this stretch there is a regular cataract. This course is maintained generally down to the confluence of the Durra river, which comes from a course slightly north of east, and at the end of March the Durra carries about 3 cubic metres per second.[1]

"From the confluence of the Didessa with the Blue Nile down to the Durra river, I reckon it is approximately 23 miles. There are frequent rapids on this stretch of river, and one particularly deep gorge just above a very large sandy khor.

"From the Durra river to the Gojabba river, which in dry weather is a succession of pools, is approximately 15 miles. Due west of Gojabba river, and about 2 miles from the left bank of the Blue Nile, stands Mount Gumbi, and 5 miles further is the village of Yimbi. In this stretch of river there are not so many rapids, although a few of them are very long ones, and the bed of the river is made up of gravel-banks, deposited on rocks.

"Wamboro plateau lies in lat. 10° 2′ N., and about 8 miles north-east of the Blue Nile.

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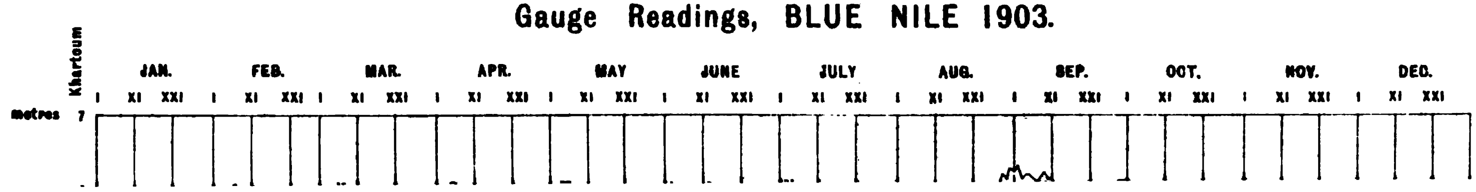
[1] The letter says "per minute," but this would make the flow almost imperceptible.

Gauge Readings, BLUE NILE 1903.



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" From Gojabba river to Abu Timbohor is approximately 30 miles, and the general direction of the river is 20° west of north. About a mile below Gojabba is a heavy cataract, and after this, with the exception of one rapid, it enters a rocky gorge, but is deep and flows quietly along. When it reaches the head of Abu Timbohor's villages, it makes a sharp bend due west for about 3 kilometres, and then resumes a course of 12° west of north, enclosing an island of 300 acres.

" Opposite Abu Timbohor's head village is a large mountain (name unknown) about 3 kilometres north-west of the confluence of the Dabus river with the Blue Nile. About 24 kilometres away to the east lie the Gum Gum mountains.

" From Abu Timbohor to Yaring is a distance of approximately 50 kilometres, and the course of the river is 12° west of north. There are fewer rapids, and the river is rather gorgy all the way.

" The Bellus (Bolassa) river joins the Blue Nile about 11 kilometres above Yaring, which is about 3 kilometres further up the river than Bambok's village."

The river called Bolassa, or Yesien,[1] was visited by Schuver in May, 1882, when he marched along the last 49 kilometres of it until it joined the Blue Nile. He describes this last permanent tributary of the Blue Nile, as a fine winding stream of clear water which then (May 20) was at its lowest, and without a perceptible current It lay between high banks of grey granite. On May 22 1882 the river began to rise and the water to become muddy, while the Blue Nile water had become so earlier.

The next tributary after the Didessa on the left bank is the Dabus, or Yabus, which rises in the Beni Shangul hills, and, flowing northwards, joins the Abai where it leaves the Abyssinian mountains and turns northwards towards Famaka. Weld Blundell[2] describes it as a fine river flowing in a deep valley between hills 650 metres high; it was about 200 metres wide and 1 metre deep when he crossed it in lat. 10° 13′ N. at the beginning of May, 1899.

The Tumat joins the Blue Nile 6 kilometres down-stream of Famaka. It has been described incorrectly as carrying water throughout the year,[3] but Schuver describes seeing the first water of the flood come down its bed near Jebel Ghezan, on the road from Famaka to Beni Shangul, in lat. 10° 45′ N., at the end of May, 1881.[4] Marno[5] states

[1] Schuver, Pet. Mitt., Erganz. 72, p. 79. Gotha, 1883.
[2] Geog. Jour., 1900, p. 31.
[3] Bull. Soc. Geog., 1843, 19, p. 99.
[4] "Reisen in oberen Nilgebiet," Pet. Mitt., Erganz. 72, p. 1. Gotha, 1883.
[5] Pet. Mitt., 1873, p. 250.

that in the dry season water may everywhere be found in the river-bed at a short distance from the surface. All these larger tributaries must bring down a large volume in the rainy season, and most of them contribute a certain amount throughout the low stage of the Blue Nile also, so that the supply in the months of the spring and the early summer depends on them and the Abai itself. As the Abai was found by Dupuis[1] on January 31, 1903, to be discharging only 42 cubic metres per second where it left Lake Tsana, the winter and spring supply of the Blue Nile must come mainly from its tributaries. In marked distinction to the left-bank tributaries are those of the right bank; with a steep slope and a short course, they are torrential in character, and rise and fall rapidly, but after the rainy season, soon fall to very small dimensions. The Rabad and Dinder which rise in the western foothills of Abyssinia, and flow north-west to join the Blue Nile above and below Wad Medani respectively, are larger streams, and are of importance when in flood.

Pruyssenaere[2] measured the discharge of both of these, as well as of the Blue Nile at Karkoj in 1864, at highest flood, and gives the following values :—

	Width.	Mean depth	Sectional area	Mean velocity.	Discharge.
	m.	m.	m^2	m. p. s.	m^3 p. s.
Blue Nile (Karkoj)	435·0	7·10	3088	1·90	5867
Dinder (Wold Abyad)	163·4	4·58	746	1·90	1454
Rahad (Wold Es)	83·2	3·14	261	2·05	535

In 1864 the Dinder was flowing with a feeble current on February 18, and soon afterwards ceased to flow.[3] They both rise about the end of May or the beginning of June. There are no gauges on either of these rivers, so no more recent data are available.

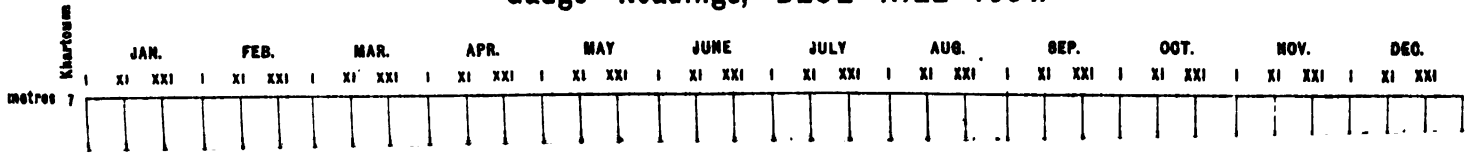
The right-bank tributaries therefore contribute very little to the low-stage supply; they have for the most part, not only smaller catchment basins, but a shorter rainy season. The left-bank tributaries draining Shoa, Wallega, and northern Kaffa have larger basins and longer rains, so that if the September and October rains are above the average, these streams will supply a larger volume to the Nile at low stage, as also will the Sobat, and, as has already been mentioned, these are the determining factors of the low-stage supply.

[1] Report upon Lake Tsana, p. 19 (in A report on the Basin of the Upper Nile). Cairo, 1904.

[2] Pet. Mitt., Ergänz. 51, 1877, p. 45.

[3] The Dinder is not a perennial stream, as stated in Scot. Geog. Mag., 1904, p. 480, except near its source.

Gauge Readings, BLUE NILE 1904.



On leaving the Abyssinian Hills the Blue Nile, as the Abai is now called, turns westwards as far as Famaka and then takes up the generally north-west direction which it keeps till Khartoum is reached. Just below Roseires, where the river ceases to be navigable for steamers, it is 400 metres wide at low stage and 600 in flood, varying from these dimensions to 250 metres in particularly narrow places. The banks are usually 6 to 8 metres above the flood level on the eroding side, the other being more shelving and often flooded at high Nile. Islands are common but none of them are large, few being more than a kilometre long. From lake Tsana to the western frontier of Abyssinia the course of the Abai has, as we have seen, been determined by the rocks through which it has cut its way, faults, jointing, harder beds, and other such conditions having had full effect. Now the river opens out on to an alluvial plain of comparatively low slope, the fall from Roseires to Wad Medani being 52 metres at low stage while the straight line distance is 297 kilometres and by the river 433 kilometres corresponding to slopes of 1 in 5,660 and 1 in 8,300;[1] here with no rock walls to confine it, curves begin to form and these soon increase to typical meanders.

These curves probably move but slowly but that they do move is clear from the fact that the eroding bank has usually forest up to the edge, while on the other shore where deposit is taking place, is first a sand bank and above it a slope with grass and shrubs but on which large trees have not yet grown.[2] This meandering on the plains is even more strongly shown by the Dinder and Rahad (see Plate XXVI).[3] These streams rising in the western mountains of Abyssinia pour down in flood heavily laden with detritus a part of which is deposited in their beds where the velocity is reduced, and the effect of this is well seen east of Sennar where the Rahad and Dinder have so raised their beds that their flood waters overflow the plains between them, and drainage lines join the two valleys; these rivers finally join the Blue Nile below and above Wad Medani respectively. Beyond this point the river runs through a belt of country about 5 kilometres wide in which grow thornbush and similar plants, and the river moves from side to side as the erosion of its bends proceeds. From Wad Medani to Khartoum the Nile falls about 15 metres in a distance of 206 kilometres corresponding to a slope of 1 in 13,500; the river is wider and less sharply curved, and flows in a well defined valley; finally it turns abruptly westwards and

[1] See p. 226.
[2] Note by Mr. J. I. Craig in November 1904.
[3] Reduced from Sheet 55. O of Map 1489 scale. 1 : 250,000. Topog. Section Gen. Staff.

meets the White Nile at right angles (Plate XXIII). The Blue Nile like the Atbara and to a certain extent the Rahad, Dinder and Sobat flows in a deep-cut well-defined section (Plate XXII*b*.) and does not overflow its banks but is at some distance below them even in flood. While the Sobat carries but little matter in suspension the Blue Nile and the Atbara are heavily silt-laden especially the latter, and it is only the heavy rains on the Abyssinian tableland which by rapidly increasing their volume enable them to carry their load without raising their beds and forming inundated flood plains, except in the case of the portion of the Rahad and Dinder already mentioned.

Consequently natural embankments are not being built up by deposition on either bank, and the plain, in which the Blue Nile flows, slopes gently upwards from its banks to the watershed between it and the next main drainage line.

Until a much more accurate knowledge of the topography of Abyssinia is attained, the length of the Blue Nile can only be approximately determined. The following table gives the length and slope of several reaches but not till down-stream of Roseires can the data be considered as of any accuracy.

Place	Distance	Distance from Lake Tsana	Altitude above sea level	Slope 1 metre in
	km.	km.	m,	
Source	—	—	..	..
Lake Tsana	240	—	1755	..
Alata Bridge..	32	32	..	..
Junction with Didessa.	560	592	..	..
Roseires..	309	901	439·35 [3]	..
Sennar	287	1188	405·68 [3]	8,500
Wad Medani..	146	1334	387·42 [3]	8,000 [1]
Khartoum [2]	206	1540	372·12 [3]	13,500

Although the flood of 1903 was not a high one, indeed in volume it was 11% short of a normal flood (p. 231) and its maximum height at Aswan was 18 centimetres below the average, still some of the velocities which were measured in the Blue Nile were considerable; the highest mean velocity of 2·796 metres per second was recorded on August 21 and on that day the maximum velocity at $\frac{6}{10}$ depth from the surface was 3·418 metres per second. Wire sounding apparatus was not at the time available, and a thin line with a 16 lb. (7·25 kilogr.) weight was used, so that it was difficult during the highest flood to

[1] This slope appears to be too steep for the middle reach in which the river meanders greatly.
[2] The zero of the Khartoum gauge is taken as being 370·0 metres above sea-level.
[3] These altitudes refer to the water surface on 1.12.05.

PLATE XXV.

Fig. 1.

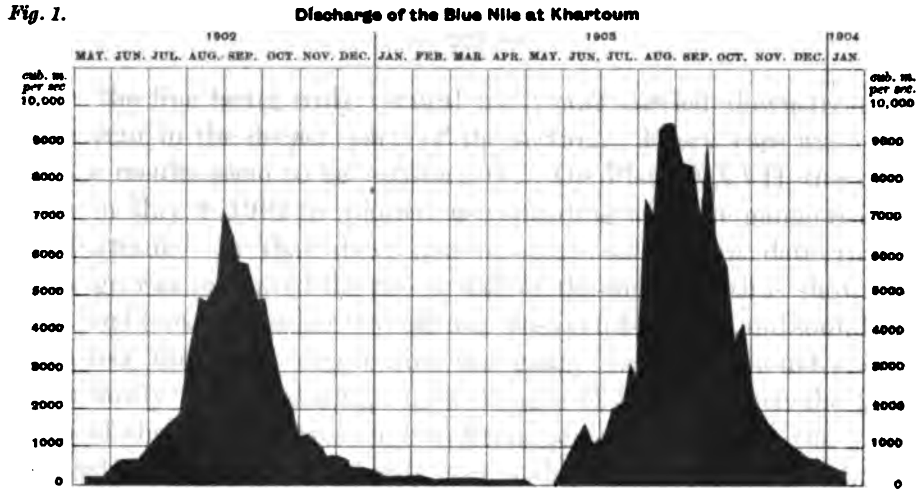


Fig. 2.

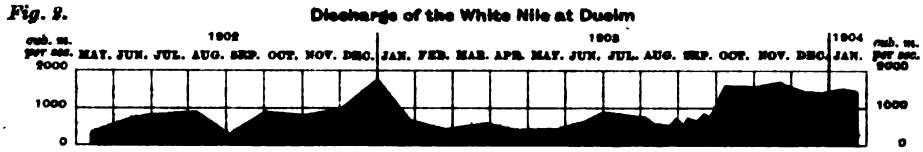
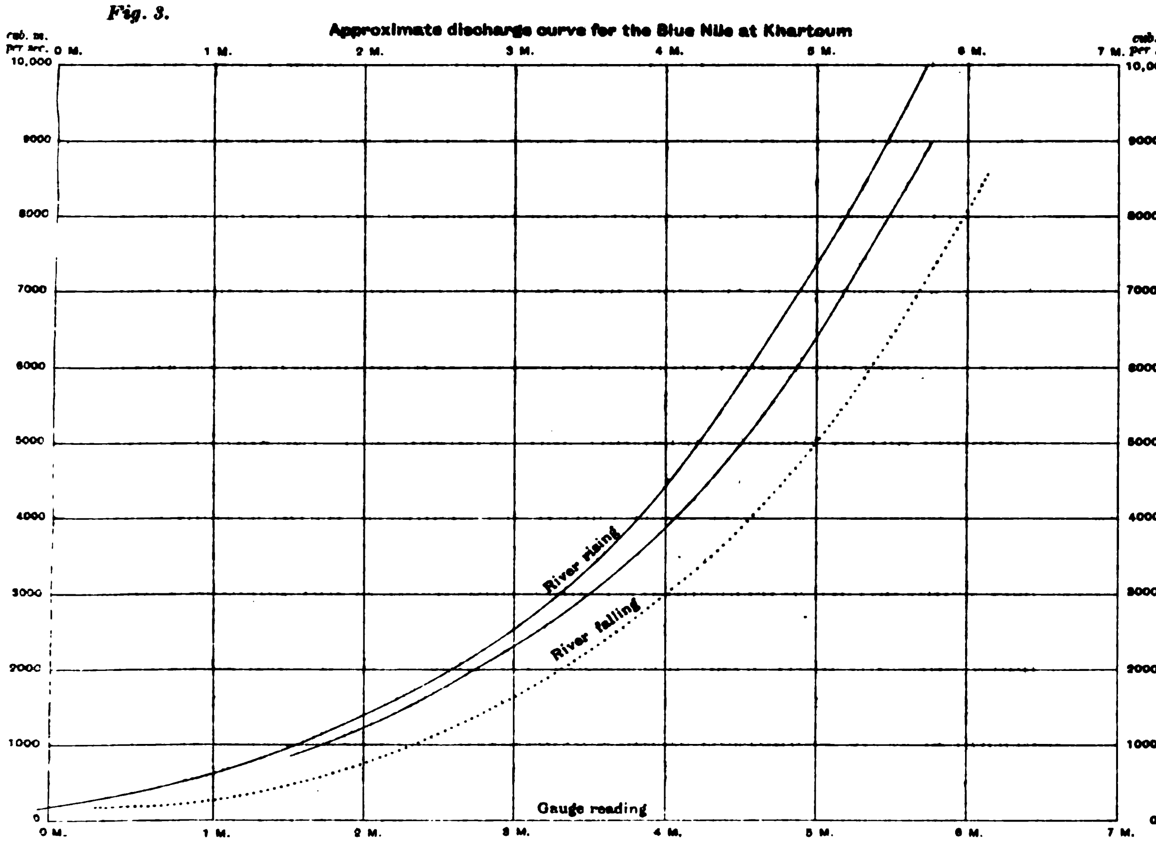


Fig. 3.



SURVEY DEPT.

PLATE XIV

Fig. 1.

Discharge of the Blue Nile at Khartoum

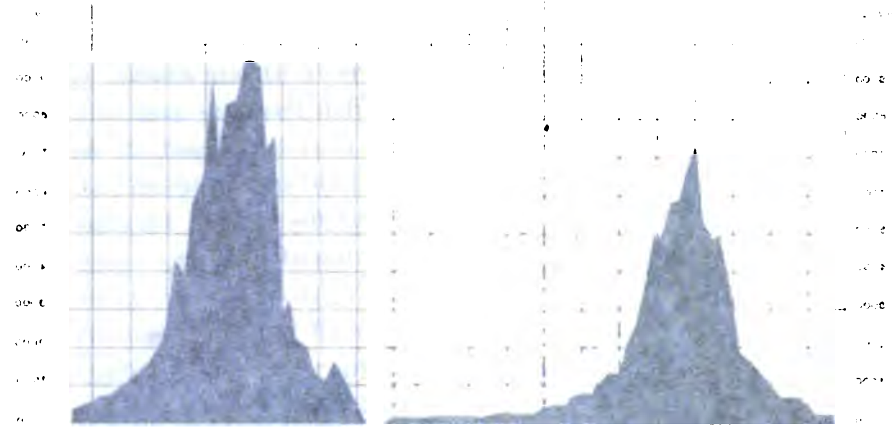


Fig. 2.

Discharge of the White Nile at Duem

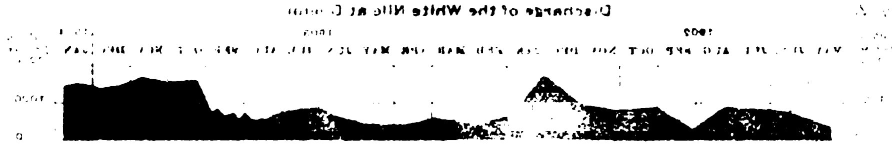
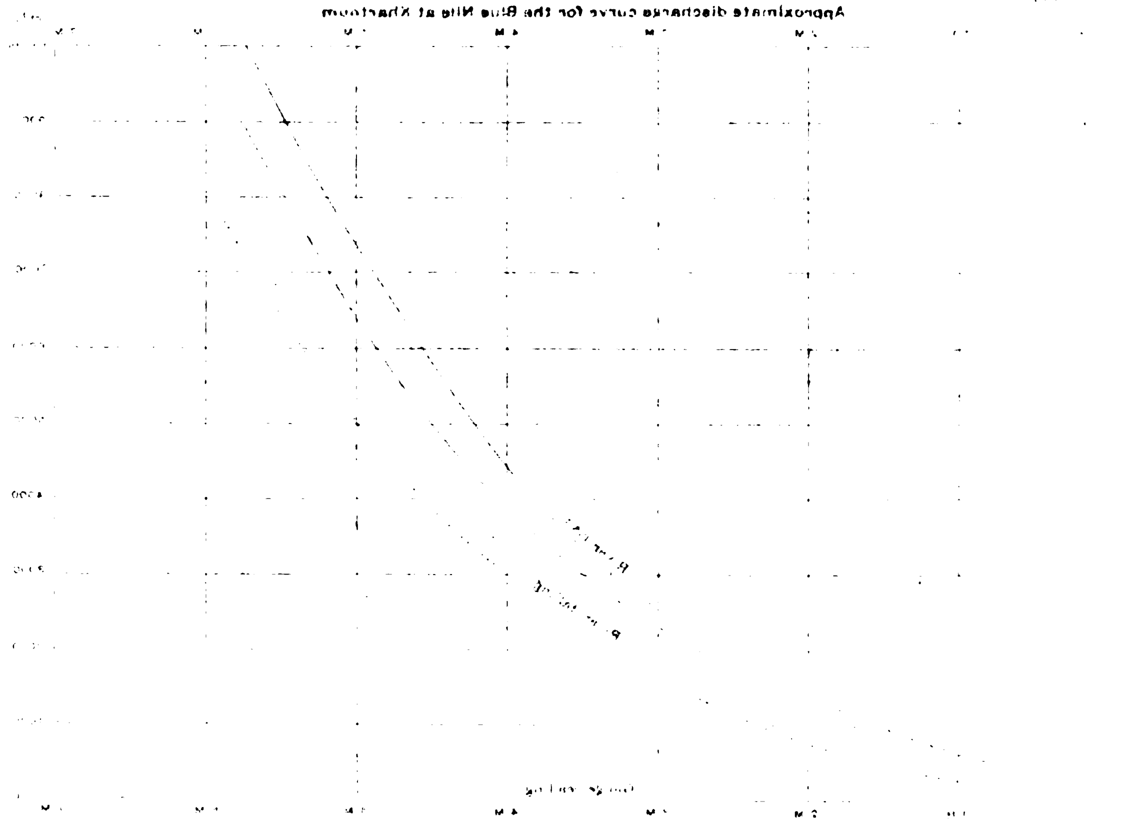


Fig. 3.

Approximate discharge curve for the Blue Nile at Khartoum



ensure the line being truly vertical as it was carried downstream by the current in the deeper parts of the section. Every care was taken and the results seem to be satisfactory. On Plate XXVII the mean depth on May 9 1902 is plotted as coinciding with the gauge reading at Khartoum[1] on that date, and on each subsequent date that a discharge was measured the rise or fall of the mean depth is shown by the dotted line. If neither deposit nor erosion takes place and soundings are correct the mean depth and the gauge readings should change concordantly[2] except during rapid changes of level, as then the mean depth of the section corresponds to a time several hours after the gauge was read since it is observed only once a day at 8 a.m. As the line of the section was changed on May 28, 1903 the mean depth of that date is also plotted to coincide with the gauge reading of that date. If now the mean depth line on Plate XXVII rises above the gauge readings line either the soundings have given too large results or the river has deepened its section; if it passes below the gauge readings line the river has deposited material and the section has become shallower.

Taking the year 1902, a slight filling of the section took place early in the flood which soon after was corrected by erosion; shortly before the maximum height was reached a marked deposition took place followed by erosion which restored original conditions and immediately after the maximum considerable deposition again occurred which material was to a great extent removed about the end of December. This was a year of exceptionally low flood (see p. 231) and the mean velocity of the Blue Nile at Khartoum never rose above 1·745 metres per second.

In 1903 when the flood was a better one and the maximum mean velocity at Khartoum was 60 per cent. above that of the previous year, there was a very different condition of affairs. It is unfortunate that the sections are not identical but the establishment of the buildings of the Sudan Development Company necessitated using a new section 348 metres down-stream of the former one.

In this year the short rise of June 17 caused a slight scour which the following fall refilled, but scour recommenced with the quick rise of the first ten days of August, only to be succeeded by a well marked period of deposition lasting for about ten days from the time when the rate of rise appreciably moderated, and agreement between gauge and mean depth values is not reached until September 4. It is noticeable that this period when the mean depth was surprisingly low

[1] The gauge is about 1·25 kilometres below the line of section.
[2] Strictly true of a rectangular section but that of the Blue Nile approximates to this fairly well, see Plate XXIII*b*.

included the four highest values of the mean velocity so that if the soundings were too large on account of the velocity of the current, the real deposit was even greater than that deduced above. This period of deposition agrees closely with that of 1902 in occuring when the rapid rise of the river is moderating and the maximum gauge reading is approaching.

Immediately after the maximum stage of the flood was past erosion of the section commenced and the divergence of the two curves reached a maximum (2 metres) on September 25 which was not reduced to small dimensions until the end of October. During this period the mean velocity varied from 1·879 metres per second to 0·945 which certainly caused no serious difficulty in sounding, so that there was actually considerable erosion as the river fell from its maximum height which was balanced by deposition later. In this year it would seem that by the end of the year the bed of the Blue Nile near Khartoum was distinctly higher than twelve months before.

It may be that the mean depths when the velocity was highest are somewhat too large but this cannot be proved so that it is preferable to use the figures as they stand, since they appear to be reliable.

In 1902 and 1903 a series of discharges of the Blue Nile were measured at a point about 5 kilometres up-stream of Khartoum.[1] Velocities were measured by means of a Price's current meter and were determined at points 45-50 metres apart along the section, while soundings were taken every 15 or 16 metres. The distances were measured along a hawser stretched across the river by means of which a boat was passed across; these distances were subsequently corrected to agree with the known width of the section. The results are given in the following table.

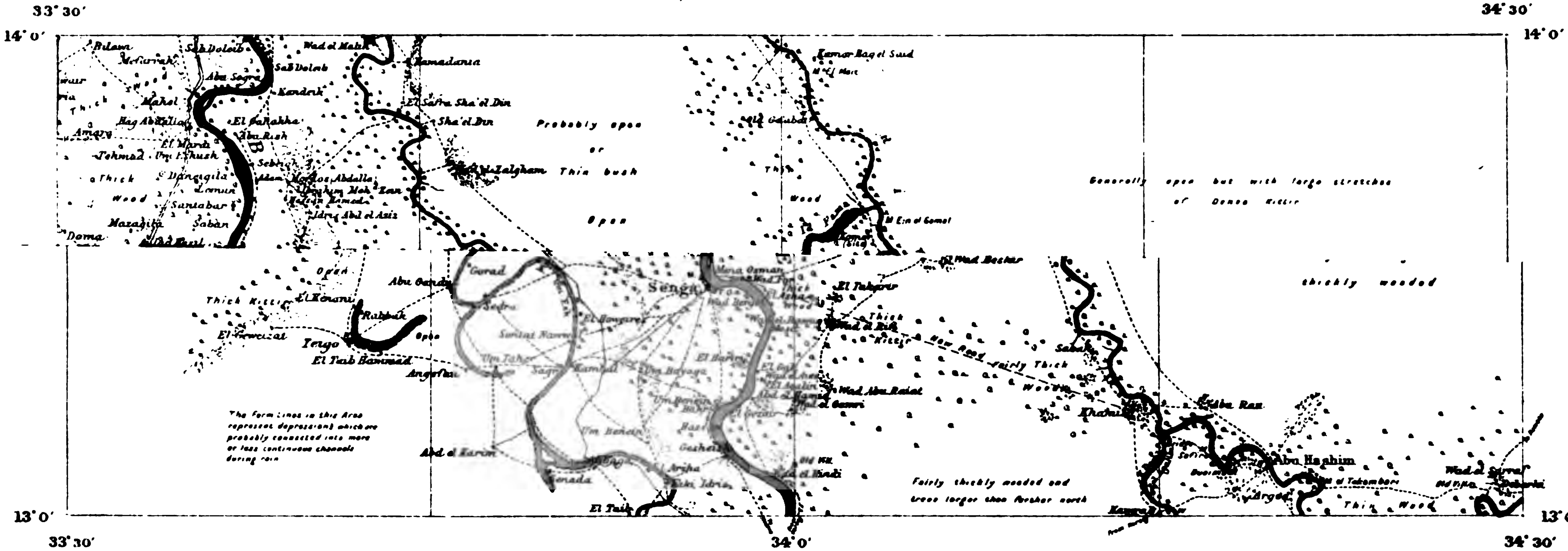
BLUE NILE.

Date.	Width.	Mean depth.	Section area.	Mean velocity.	Discharge.	Gauge at Khartoum.
	m.	m.	m²	m. p. s.	m.³ p. s.	m.
1902						
9 May	347	4·34	1420	0·120	184	−0·05
23 „	332	4·38	1390	0·124	194	0·16
6 June	342	5·51	1774	0·314	604	0·76
20 „	351	5·56	1829	0·372	695	1·06
27 „	351	5·83	2010	0·393	837	1·30
4 July	351	6·27	2044	0·507	1082	1·75
11 „	354	6·19	2230	0·616	1453	2·07
18 „	354	6·40	2322	0·668	1612	2·33
25 „	356	6·60	2456	0·702	1885	2·64

[1] See Report on the basin of the Upper Nile, Appendix. V., p. 45, Cairo, 1904, for measurements made before this date, see Chap. VII.

PLATE XXVI.

The Meanders of the BLUE NILE, the DINDER, and the RAHAD RIVERS.



From I.D., W.O., Map No. 1489. Sheet 55 K.

Scale $\frac{1}{500,000}$

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BLUE NILE—*continued.*

Date	Width.	Mean Depth.	Section area.	Mean velocity.	Discharge.	Gauge at Khartoum.
	m.	m.	m.²	m. p. s.	m³ p. s.	m.
1902						
1 August	358	7·81	2858	1·098	3420	3·34
8 „	360	8·60	3274	1·344	4880	4·20
15 „	365	9·00	3314	1·322	4720	4·50
22 „	365	8·52	3248	1·545	5540	4·93
29 „	370	9·82	3697	1·745	7180	5·34
5 September	364	9·91	3852	1·502	6580	5·27
12 „	364	9·17	3416	1·620	5800	5·35
19 „	364	8·30	3272	1·590	5760	5·30
26 „	362	7·70	2990	1·428	4860	5·10
3 October..	362	8·28	2935	1·470	4880	5·03
10 „	359	7·23	2710	1·096	3250	4·45
17 „	357	6·43	2441	0·931	2460	3·73
24 „	316	6·54	2228	0·833	2030	3·40
31 „	295	6·84	2134	0·535	1244	3·00
7 November	291	6·50	2024	0·580	1272	2·77
14 „	289	6·54	1942	0·461	1035	2·48
21 „	289	6·01	1864	0·463	802	2·23
28 „	287	6·26	1864	0·394	787	2·11
5 December	286	5·80	1812	0·323	654	1·94
12 „	284	5·70	1723	0·288	486	1·80
23 „	282	6·06	1727	0·281	746	1·58
1903						
2 January	281	5·65	1664	0·216	348	1·39
9 „	280	5·45	1589	0·182	270	1·22
16 „	277	5·28	1539	0·166	248	1·09
23 „	285	5·18	1554	0·178	250	0·94
6 February	275	4·98	1415	0·168	226	0·60
20 „	275	4·74	1353	0·114	152	0·39
6 March	273	4·49	1283	0·162	202	0·19
20 „	270	4·32	1231	0·182	201	0·04
3 April	270	4·56	1139	0·124	132	—0·12
17 „	268	4·24	1209	0·132	154	—0·16
1 May	268	4·16	1169	0·106	121	—0·22
8 „	268	4·22	1200	Nil.	Nil.	—0·23
15 „	268	4·00	1070	Nil.	Nil.	—0·26
22 „	269	4·02	1080	Nil.	Nil.	—0·09
Change of line of section.						
28 May	383	3·57	1510	0·235	374	0·53
6 June	385	4·50	1859	0·505	970	1·40
19 „	389	5·05	2140	0·680	1500	1·90
26 „	388	4·83	1998	0·524	1089	1·58
3 July	389	4·92	2037	0·628	1314	1·78
10 „	391	5·60	2296	0·803	1952	2·48
17 „	392	5·70	2393	0·882	2267	2·75
24 „	395	6·22	2636	1·177	3183	3·40
31 „	397	6·62	2594	1·084	2870	3·45
5 August	418	8·30	3528	2·103	7584	4·60
10 „	420	9·26	3814	1·715	7100	5·06
14 „	423	9·00	3808	2·456	9340	5·65
21 „	407	8·06	3381	2·796	9519	5·90
28 „	406	8·60	3569	2·566	9544	6·05

BLUE NILE—*continued.*

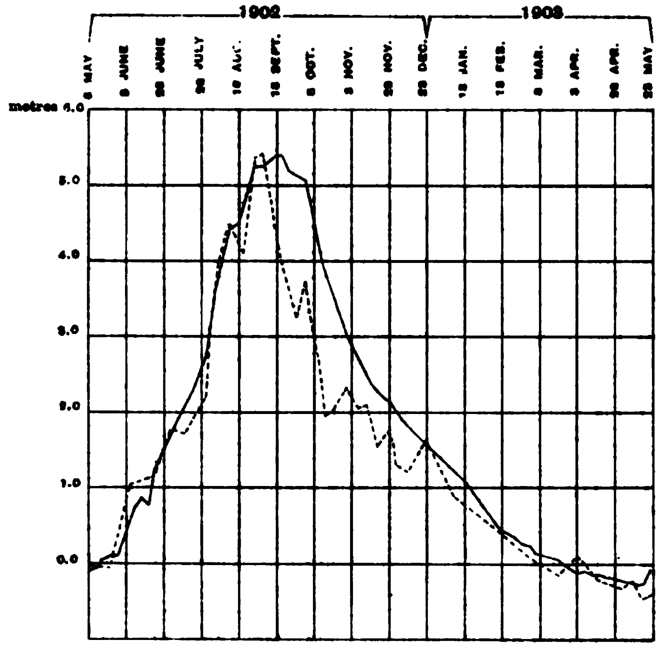
Date	Width.	Mean Depth.	Section area.	Mean velocity.	Discharge.	Gauge at Khartoum.
	m.	m.	m²	m. p. s.	m³ p. s.	m.
4 September	408	9·25	3872	2·094	8474	6·20
11 „	409	9·96	4094	1·960	8385	6·15
18 „	406	9·28	3821	1·814	7070	5·88
25 „	408	11·20	4594	1·879	8965	6·08
2 October..	404	10·40	4218	1·518	6581	5·53
9 „	401	9·50	3788	1·493	5749	5·15
16 „	398	8·15	3234	1·105	3612	4·45
23 „	398	8·40	3326	1·210	4098	4·56
30 „	402	7·34	3087	0·945	2893	4·00
6 November	400	6·85	2831	0·800	2275	3·50
13 „	398	6·56	2620	0·679	1790	3·10
20 „	398	6·19	2504	0·579	1456	2·65
4 December	392	5·77	2351	0·472	1102	2·35
18 „	375	5·62	2212	0·356	789	1·90
25 „	388	5·60	2262	0·318	722	1·88
1904						
1 January	379	5·48	2152	0·281	604	1·80
15 „	361	5·33	2020	0·242	488	1·59

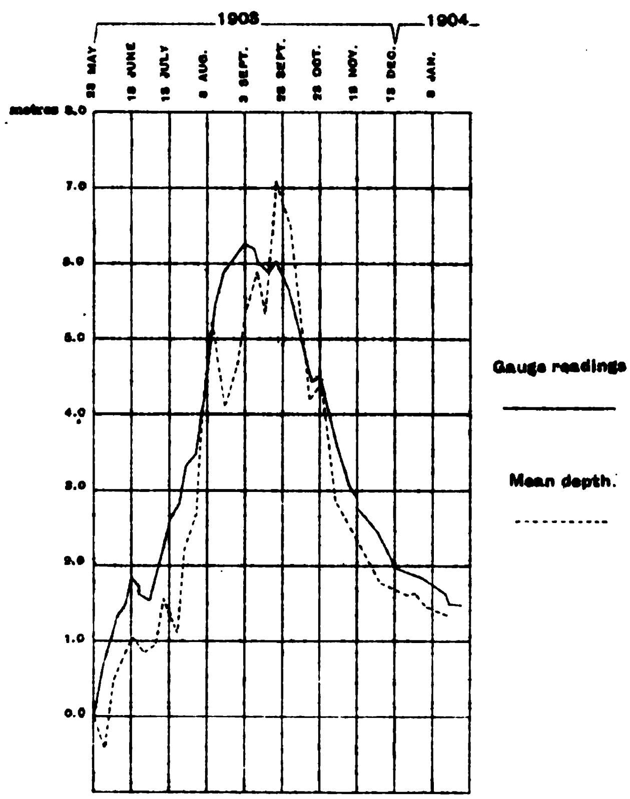
From the weekly discharges the mean discharge per second can be readily obtained for successive 5 day periods and these are given in the following table, together with the total volume discharged during each such period.

1902 Flood	Mean discharge in cubic metres per second	Volume discharged during period in millions of cubic metres
July 1- 5	1100	475·2
„ 6-10	1330	574·5
„ 11-15	1480	639·3
„ 16-20	1600	691·2
„ 21-25	1800	777·6
„ 26-31	2700	1399·6
August 1- 5	4030	1741·0
„ 6-10	4720	2039·0
„ 11-15	4900	2116·8
„ 16-20	5200	2246·4
„ 21-25	6000	2592·0
„ 26-31	6900	3577·0
September 1- 5	6950	3002·4
„ 6-10	6450	2786·4
„ 11-15	6100	2635·2
„ 16-20	5900	2548·8
„ 21-25	5450	2354·4
„ 26-30	5020	2602·4
October 1- 5	4830	2086·6
„ 6-10	4040	1745·3
„ 11-15	3100	1339·2
„ 16-20	2650	1144·8
„ 21-25	2170	937·4
„ 26-31	1650	855·4
	Total	42,907·9

PLATE XXVII.

GAUGE READINGS AND MEAN DEPTH OF THE BLUE NILE AT KHARTOUM.

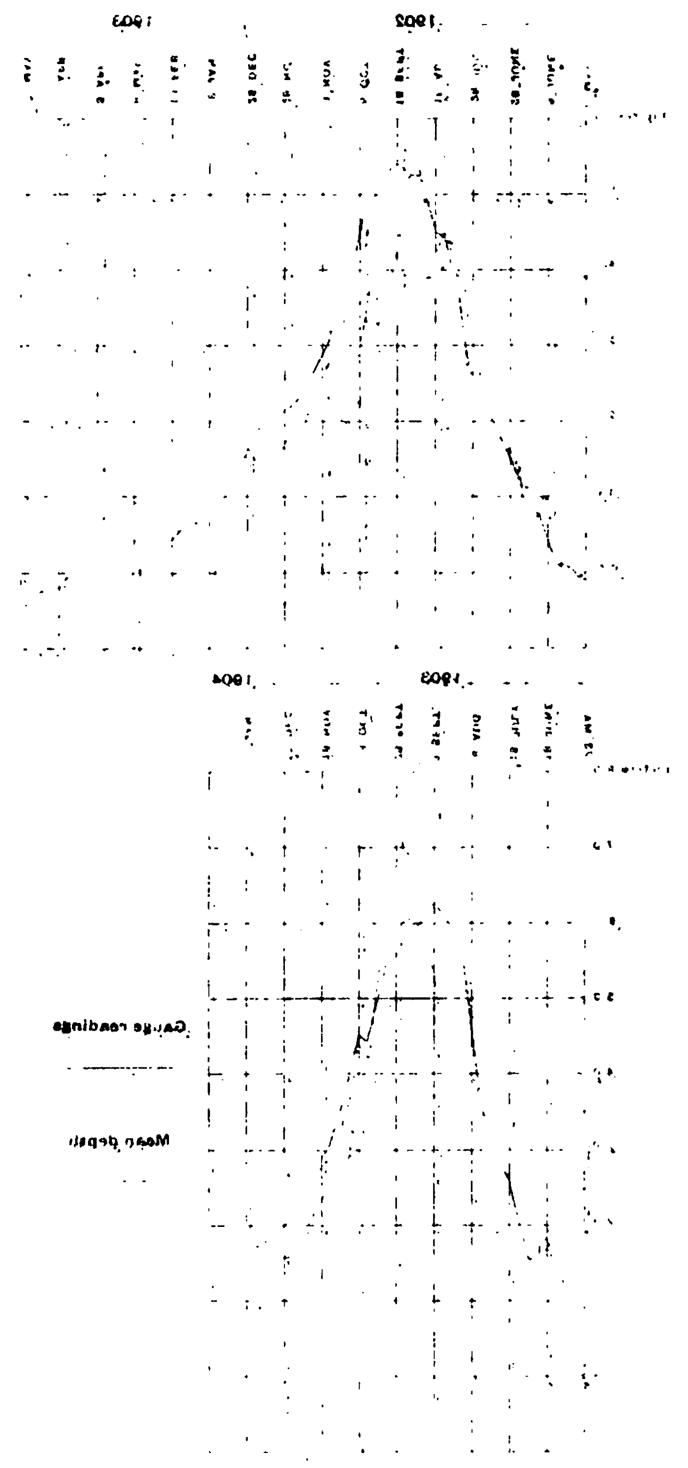




SURVEY DEPT.

PLATE XXVII

GAUGE READINGS AND MEAN DEPTH OF THE BLUE NILE AT KHARTOUM



For a similar period in 1903 we obtain in the same way the following table :—

1903 Flood	Mean discharge in cubic metres per second	Volume discharged during period in millions of cubic metres
July 1- 5	1290	558·8
„ 6-10	1790	771·6
„ 11-15	2190	944·8
„ 16-20	2600	1123·2
„ 21-25	2950	1274·4
„ 26-31	2950	1529·3
August 1- 5	5220	2225·0
„ 6-10	7250	3132·0
„ 11-15	8250	3564·0
„ 16-20	9420	4069·4
„ 21-25	9500	4138·6
„ 26-31	9500	4950·7
September 1- 5	8850	3823·2
„ 6-10	8400	3628·8
„ 11-15	7950	3134·4
„ 16-20	7450	3218·4
„ 21-25	8250	3564·0
„ 26-30	8100	4199·0
October 1- 5	6700	2894·4
„ 6-10	5800	2505·6
„ 11-15	4850	2095·2
„ 16-20	4150	1792·8
„ 21-25	3850	1663·3
„ 26-31	3150	1632·9
	Total	62,761·8

Thus the volume of the Blue Nile flood of 1902 was to that of 1903 approximately as 42,908 to 62,762, or as 0·68 to 1·00.

They may be compared with previous years by means of the Wadi Halfa gauge records, by taking the mean of the readings for each day for the fifteen years 1890-1904, and noting the difference between these mean values and the readings of 1902 and 1903. To shorten the table, the mean difference for each month only is given—

Month	Mean difference in centimetres from mean readings of 1890-1904: 1902	1903
	centimetres.	centimetres.
July	− 77	−16
August	−198	−67
September	− 90	+ 8
October..	− 58	+26
Mean	−106	−12

so that 1903 may be considered as rather below an average flood, while that of 1902 was an extremely bad one.

Before leaving the Blue Nile, the rate of transmission of the flood wave should be considered. Data for this purpose are not very ample, but they will suffice to form an estimate of the time which elapses between the rainfall entering the tributaries and reaching Khartoum. On Plate XXIII and XXXVI*a* are plotted the flood curves of the Blue Nile from the gauge readings at Roseires, Sennar, Wad Medani, Khartoum, Berber, Wadi Halfa, and Aswan for the flood of 1903, and from them the following data are taken:—

River at Roseires.	Date.	Days taken for water to travel.		
		Roseires to Sennar 287 km.	Sennar to Wad Medani 146 km.	Wad Medani to Khartoum 206 km.
Fell	May 31	3	1	3
Rose	June 4	2	2	3
Fell	„ 12	3	1	2
Rose	„ 25	2	2	2
Fell	July 8	3	2	3
Rose	„ 12	3	1	2
Fell	„ 17	3	0[1]	2
Rose	„ 27	1	2	2

Mean time Roseires to Sennar 2·5 days, or 112 km. per day.
„ „ Wad Medani 4 „ 108 „
„ „ Khartoum 6·4 „ 100 „
or about 10 days from the centre of its basin.

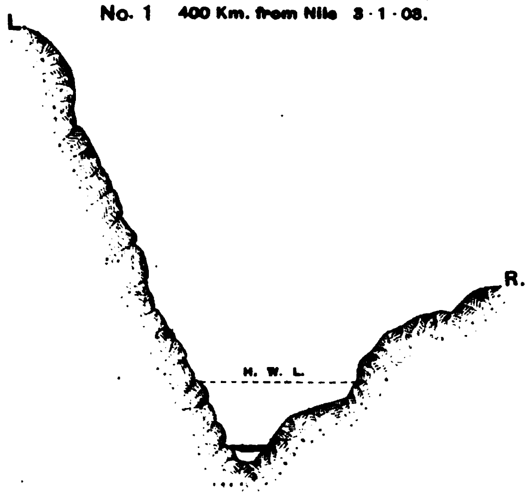
Atbara River.—The last tributary of the Nile is the Atbara which joins it 40 kilometres upstream of Berber after a total course of about 1266 kilometres. It rises as the Takazze in the Lasta hills lat. 12° 7′ N. approximately, close to the eastern escarpment of Abyssinia and rapidly deepens its valley into a steep-sided ravine deeply cut into the basalt plateau until only 16 kilometres from its source it is flowing in a ravine 600 metres deep;[2] at some 50 kilometres east of the mountains of Debra Tabor it turns northwards being joined by numerous small tributaries, and others like the Tserare and the Ghiva which are large streams, carrying a considerable volume in the rainy season. In about lat. 13° 12′ N., near where the road from Adua to Gondar crosses it, the Takazze turns westwards and following a general direction somewhat north of west finally, under the name of

[1] As the gauges are only read once a day it is not always possible to determine with accuracy the time taken by the flood wave.

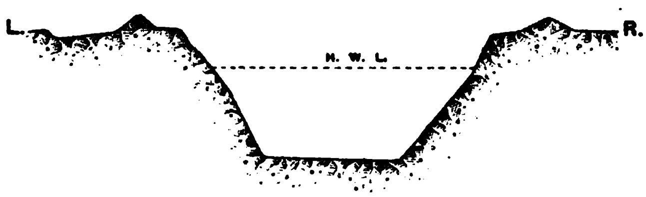
[2] Markham Jour. R. Geog. Soc. 1868, p. 42.

SECTIONS OF RAHAD RIVER

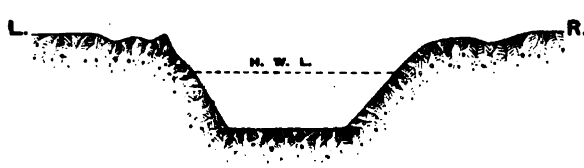
No. 1 400 Km. from Nile 3 · 1 · 03.



No. 2 Khor Abu Segheir, 20 Km. from Nile 13 · 12 · 02.



No. 3 Abu Haraz, 200 m. from Nile 12 · 12 · 02.



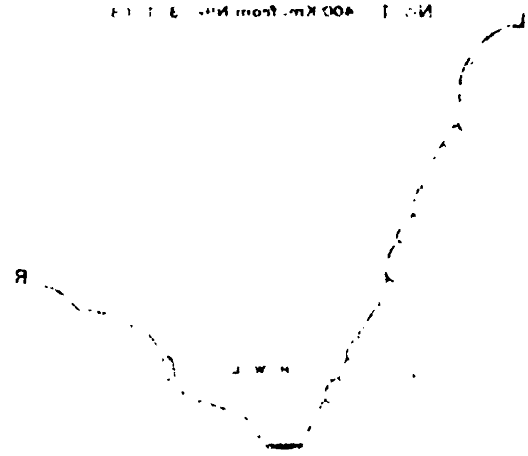
HORIZONTAL SCALE 1 : 2,000
metres 20 10 0 20 40 60 80 metres
yards 20 10 0 20 40 60 80 yards

VERTICAL SCALE 1 : 500
metres 5 0 5 10 15 20 metres
feet 10 0 10 20 30 40 50 60 feet

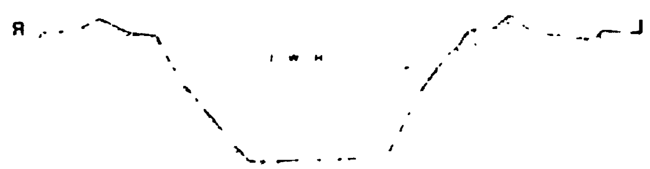
SURVEY DEPT.

SECTIONS OF RAHAD RIVER

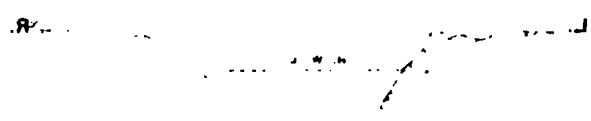
No. 1 400 Km. from Nile [illegible]

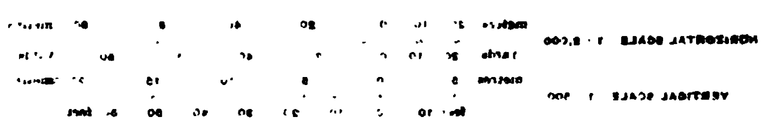


No. 2 Khor Abu Sogheir 20 Km. from Nile [illegible] 12 02.



No. 3 Abu Haraz 200 m from Nile 12 [illegible]





Settit, joins the Atbara river coming from the south-east to form the main stream of the Atbara at a point 502 kilometres from the Nile. This south-eastern branch is called the Atbara as far as Gallabat, shortly above which point the two streams of the Goang and the Gandoa join it. Though the southern branch bears the name of the main stream, the Takazze-Setit is in reality the upper portion of the Atbara of which the Bahr-el-Salam, the Goang and the Gandoa are tributaries; by its length, its volume in flood, the extent of its basin, and its effect on the regimen of the main stream it fully establishes its right to this position.

The limits of its basin on the south, where it meets the basin of the Blue Nile, have already been described. On the north they run from about Adigrat on the eastern escarpment by Adua and thence westwards very near the valley of the Mareb or Khor el Gash. After Fasher the Atbara receives no tributary of importance and the basin limit is an ill-defined line not far from the river.

Like most of the rivers of Abyssinia the Takazze is in flood in July and August, being fed by the summer rains of the Abyssinian plateau, but after October it falls rapidly and from November to May the Takazze is of small depth while the Atbara sinks to a number of separate pools which afford watering places for the Arabs of the district and their flocks.

Measurements of this river are scarce and are usually limited to breadth and depth; at low stage, when in many places the water hardly fills the bed, determinations of velocity would only mislead unless made with special precautions.

In February 1881 Rohlfs crossed the Takazze in about lat. 12° 15′ N. and made the altitude of the bed of the river at this point 1260 metres above sea level, or about 800 or 900 metres below the level of the plateau. The valley is here 300 metres wide at the bottom widening to 4·5 kilometres at the level of the plateau, and has not the very steep slope which mountain streams often have; Rohlfs makes it 12·5 metres per kilometre in this part from his aneroid observations. The flood marks showed a rise of the water-level in the rainy season of 6 metres.[1] He crossed it in March on the Gondar-Adua road where the altitude of the bed is given as 800 metres; the river was here 100 metres wide and one metre deep. The distance along the river from the upper crossing place to the lower as measured on the map[2] is about 210 kilometres while the difference of level is 460 metres which corresponds to an average fall of 2·19 metres per kilometre.

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[1] Rohlfs, "Meine Mission nach Abessinen," Leipzig, 1883, p. 291.
[2] Pet. Mitt. 1882.

Beke [1] crossed it at the first of these points apparently at the end of March 1841 and describes it as being then 20 yards wide and a foot deep.

Ferret and Galinier [2] in March 1843 crossed its valley in lat. 13° 15′ N. approximately half-way between Rohlfs' crossing-places, and described the river as 20 metres wide, one metre deep rising to 4·5 and 5·5 metres deep in flood and flowing in a deeply eroded channel 600 metres below the general level of the plateau.

Heuglin in January 1862 crossed the Takazze just below the point where it turns north-westward and describes the valley floor as 80 to 120 paces (60 to 90 metres) wide, in which the river, about 35 metres wide and a metre deep, flowed rapidly.

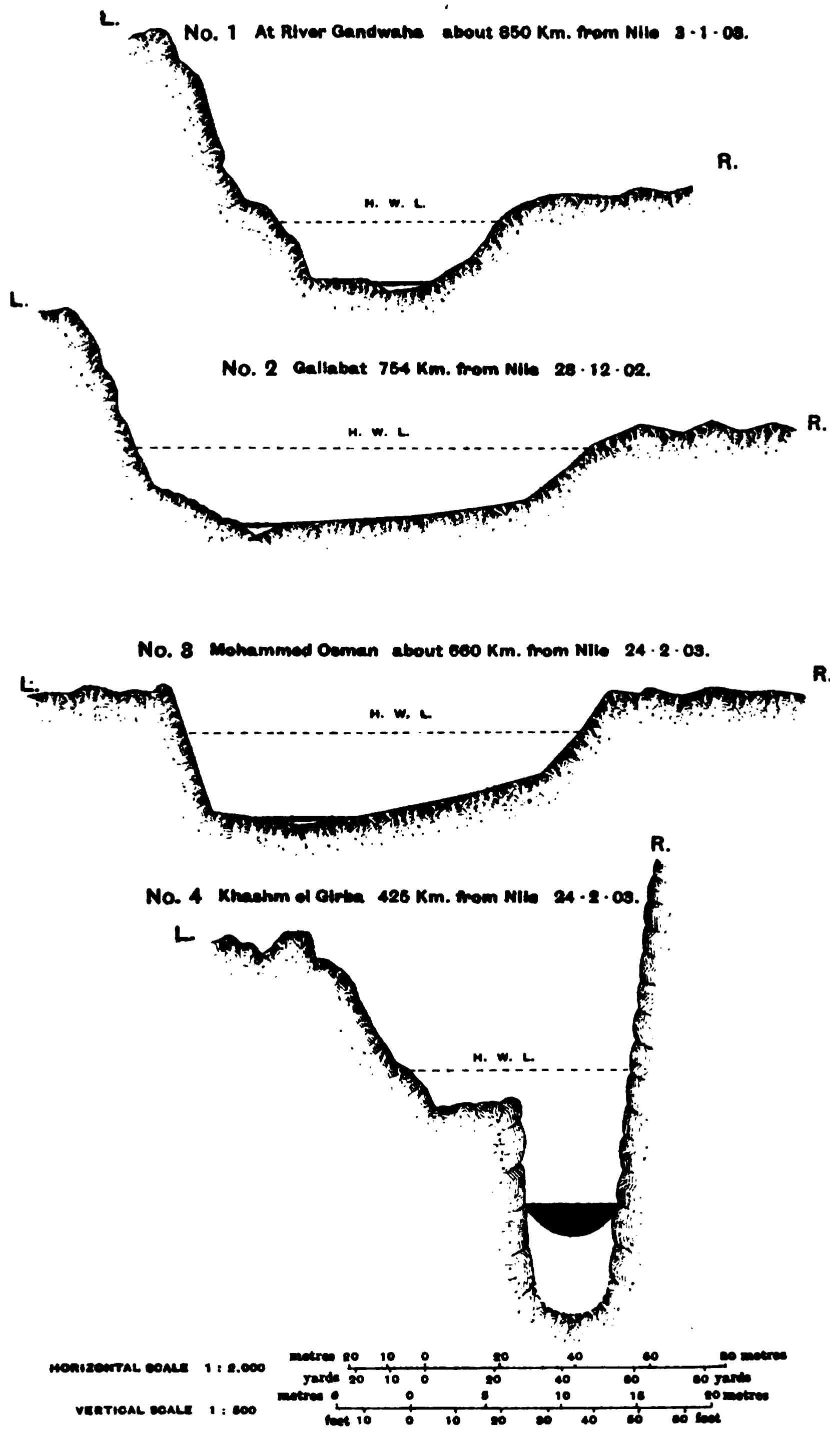
Small scale maps offer little guarantee of accuracy when river lengths have to be measured, but no survey of the Takazze valley yet exists, nor have any of the altitudes been determined more accurately than barometric or hypsometric observations admit; the following table must therefore be taken as furnishing approximate values only which will probably be considerably altered when exact determinations become available.

Place.	Distance in km.	Distance from source. km.	Altitude metres.
Source	..	..	about 3000
Where crossed by Markham	20	20	2440
„ „ „ Rohlfs[3]	120	140	1310
Junction with River Meri[3]..	20	160	1260
Where crossed by Ferret and Galinier	120	280	1005
„ „ „ Rohlfs	100	380	817
Junction with Atbara	384	764	460[4]
Khashm el Girba	77	841	455[4]
Goz Regeb	151	992	380[4]
Junction with Nile	274	1266	335[4]

The lower part of the Takazze before it joins the Atbara is known as the Settit which is about the same size as the upper portion of the Atbara at the point where they join. Recently this part of the basin has been described in considerable detail and sections of the river measured at several points,[5] thus furnishing a more accurate account of them than has hitherto been available.

[1] Proc. Royal Geographical Society, 1842. Vol. XIV.
[2] "Voyage en Abyssinie."
[3] Loc. cit. p. 191.
[4] „ „ p. 291.
[5] Dupuis from aneroid observations.—Report upon Lake Tsana and the rivers of the Eastern Sudan—in A Report on the Upper Nile. Cairo, 1904, p. 25. According to the Sudan Railway levelling the altitude of the junction of the Nile and the Atbara is 352 metres above sea-level at low stage and about 359 metres in flood. Captain S. T. Newcombe R.E. gives the slope in April 1903 from the Nile water surface to that of a pool at Hilgi, 60 kilometres upstream,

SECTIONS OF THE ATBARA RIVER



SURVEY DEPT.

The Atbara is formed by the junction of three streams, the Goang, the Bulwena and the Gandwaha, which meet at a short distance above Gallabat; of them the Gandwaha is said to be the largest and to rise about 16 kilometres from lake Tsana at an altitude of about 2000 metres. At Gallabat the Atbara is 120 metres wide and about 5 metres deep in flood, the bed being filled with boulders and coarse shingle, but by December the flow is very small, about 1 cubic metre per second in 1902, and by February there is no water flowing at all.[1]

The Atbara is joined 180 kilometres down-stream of Gallabat by the Bahr el Salam which is said to equal the Atbara in size; it also dwindles to a mere trickle of water in the early months of the year. The bed is formed of small boulders and shingle. From this point to where the Settit or Takazze joins it, 72 kilometres further downstream, the channel of the Atbara is from 150 to 200 metres wide and in flood the water is about 6 metres deep; beyond this the river lies in a deep valley occasionally as at Khashm-el-Girba, where a river gauge was cut on the rock in 1903, passing through a narrow gorge. Below this point the channel widens to 350 or 400 metres with steep clayey banks and a flood depth of about 7 metres; this section varies but little till the Nile is reached.

The climate of the upper basin of the Atbara, drained by the Takazze and the Settit rivers, is that of the Abyssinian plateau which has been already described. On the Sudan plains it varies from the places near the Abyssinian table-land with a heavy rainfall in the summer months followed by a dry season of seven or eight months to the conditions of almost absolute aridity such as are met with at Berber near the junction of the Atbara with the Nile.

The following measurements of rainfall have been made on the Sudan plains in or near the Atbara basin.

RAINFALL IN MILLIMETRES.

Gallabat.

Years	Jan.	Feb.	Mar.	April	May	Jnne	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1903 ..	..	..	..	..	..	..	173	298	134	2	0	0	[607]
1904 ..	0	0	0	2	65	131	266	169	210	37	11	0	891
1905 ..	0	0	0	0	28	168	133	274	85	118	6	0	812
Mean ..	0	0	0	1	46	150	191	247	143	52	6	0	836

as 1 in 7,600 at low stage, while the flood slope for the same distance deduced from the levelled height of flood marks at Hilgi is 1 in 5,400. If this slope of the water-table at low stage is confirmed it may mean that an appreciable amount of water passes to the Nile even then, through the sand and gravel which form the river bed.

[1] Dupuis, loc. cit.

Gedaref.

Years	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1903 ..	..	..	..	..	..	..	110	203	120	0	0	0	[433]
1904 ..	0	0	5	0	33	59	146	216	97	29	2	0	587
1905 ..	0	0	8	0	41	112	275	64	103	2	42	0	647
Mean..	0	0	6	0	37	86	177	161	107	10	15	0	599

Khashm el Girba.

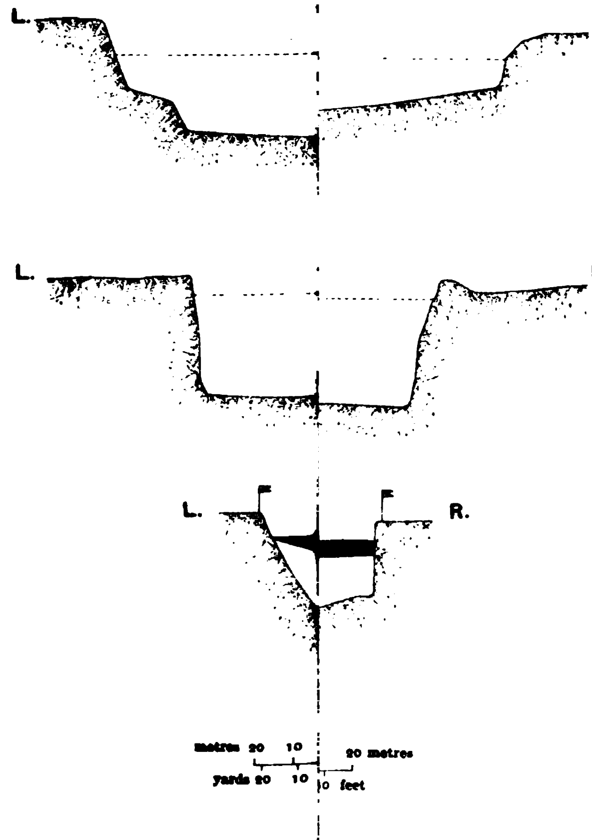
Years	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1903 ..	..	..	..	..	..	30	75	139	68	0	..	..	[312]
1904 ..	..	..	..	..	..	0	58	95	54	37	0	0	[244]
1905 ..	..	..	..	..	..	23	173	81	55	[22]	..	..	[354]
Mean..	..	..	..	..	..	18	102	105	59	20	0	0	[304]

The Takazze begins to rise with the early rains of Abyssinia in May and early in June the middle reaches of the river are affected. Here at this time owing to the deficient supply the permanent water-surface is at most points below the surface of the river bed except in the deep pools, but as the upper river rises, water flows down and raises this water surface till running water appears again in the bed of the river. This is called by the inhabitants "the swelling of the springs." The Atbara is often described as being torrential in character but this is more true of its tributaries in the upper reaches than of the river itself. Its slope is as shown above not excessively high, and when it has risen in flood it flows steadily, the sudden rises and falls which occur being due to its tributaries rising on the Abyssinian table-land and fed by the heavy rain-storms of July and August.

It is said to be more heavily loaded with sediment in suspension than the Blue Nile but only two actual observations exist; a sample taken near the junction with the Nile on August 24, 1902 gave 4759 parts per million while the highest value for the Blue Nile in that flood was 1573. Its volume varies certainly from year to year but no sufficient data yet exist to show whether its variations correspond with those of the Blue Nile; since it drains northern Abyssinia, while much, if not the greater part, of the Blue Nile water is from the southern part of the table-land it probably differs slightly from the latter.

The volume discharged by the Atbara was measured in 1902 and in 1903 but the results of the former year are not wholly satisfactory

PLATE XXIXb.



SURVEY DEPT.

being taken too close to the railway bridge, the piers of which may have caused erroneous determinations of the velocity, and as the observer was also carrying out measurements at Khartoum those at the Atbara could not be made regularly or at short enough intervals. The results are given in the table below.

In 1903 a very complete series was taken at Abu Dar 32 kilometres from the Nile, and the results are of great interest. The maximum discharge was 3088 cubic metres per second on August 30.

The gauge readings taken at this point are plotted on Plate XXX as well as the mean depth values, and the discharge diagram and curve. Looking at the values of the mean depth it will be seen that it keeps very close to the gauge readings showing no marked alteration in the river bed at this point until August 27-30 when it was eroded so as to increase the mean depth by about half a metre; this was when the velocity was highest, but as it decreased September 5-12 the section resumed its normal condition.

THE VOLUME DISCHARGED BY THE ATBARA RIVER.

Date.	Width.	Mean depth.	Area of section.	Mean velocity.	Discharge.	Atbara Bridge Gauge.
	m.	m.	m.²	m. p. s.	m.³ p. s.	m.
Taken just below the Atbara Railway Bridge.						
13 July 1902.. ..	228	3·05	715	0·447	334	0·80
20 „ „	235	3·10	770	0·832	600	1·40
27 „ „	238	2·1	543	1·217	625	..
10 Aug. „	261	4·1	1129	0·900	990	3·20
24 „ „	249	4·6	1274	1·060	1420	4·30
8 Sept. „	249	5·0	1405	1·435	2020	4·65
22 „ „	245	4·66	1244	0·621	690	..
6 „ „	270	4·35	805	0·164	152	3·60
Taken at Abu Dar 32 kilometres from the junction with the White Nile.						
16 July 1903.. ..	294	1·52	454	0·838	381	2·00 [1]
23 „ „	331	1·68	551	0·964	538	2·43
27 „ „	326	2·37	791	1·008	780	3·02
2 Aug. „	322	2·30	764	0·939	758	3·07
5 „ „	324	3·60	1204	1·203	1448	4·24
14 „ „	326	4·50	1509	1·491	2318	5·15
15 „ „	334	5·05	1742	1·621	2931	5·67
27 „ „	340	4·70	1627	1·679	2632	5·09
30 „ „	331	5·61	1879	1·609	3088	5·61
5 Sept. „	324	5·75	1956	1·435	2822	5·53
12 „ „	334	4·56	1581	1·336	2091	4·95
18 „ „	330	4·34	1441	1·161	1672	4·57
25 „ „	330	3·54	1211	1·032	1267	3·83
28 „ „	329	2·96	1010	0·876	902	3·28
2 Oct. „	327	2·86	991	0·914	925	3·24
4 „ „	324	2·67	883	0·838	754	3·01
5 „ „	323	2·50	826	0·835	703	2·82

[1] Temporary gauge at Abu Dar.

If the early rains are unsually heavy, the Atbara will bring down a large flood; but in years when the late rains are the heavier, the Atbara flood will not be so marked, since the rainbelt has moved southwards; 1874 was an instance of the first, and 1878 of the second case. In 1903 the volume discharged by the Atbara from July 16 to October 5 was to that discharged by the Blue Nile for the same period as 11,972 to 50,799, or about 1 to 4·3. It rises about the middle of June reaches its maximum about the third week in August, and then falls rapidly; from November to June much of its lower course is dry, except for isolated pools. On Plate XXXI are plotted the gauge curves, for Khashm el Girba 425 kilometres and for Abu Dar 32 kilometres from the junction with the Nile for the flood of 1903; at Abu Dar there was a temporary gauge, which was read daily while discharges were being measured. The rate of movement of flood-wave in 1903 can be deduced from a comparison of the two gauge curves of Khashm el Girba and Abu Dar until about August 20; after that the Blue Nile had risen nearly to its maximum and seems to have disturbed the regular agreement of the two curves for a while.

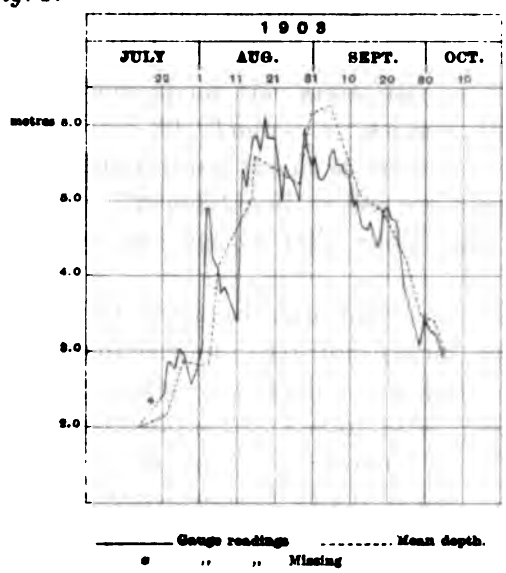
The rate of transmission of the flood-wave is deduced from the following data :—

River at Khashm el Girba.	Date.	Days taken for water to travel from Khashm el Girba to Abu Dar, 393 kilometres.	
Rose	July 26	4	Mean time of travel for a rise, 3 days. Mean time of travel for a fall, 2¼ days.
Fell	Aug. 2	2	
Rose	„ 8	3	
Fell	„ 11	2	
Rose	Sept. 15	2	
Fell	„ 17	0	
Rose	„ 26	3	
Fell	„ 27	3	

This gives a rate of 131 kilometres per day for a rise, and 157 kilometres per day for a fall. Possibly the difference is illusory and is due to gauges being read only once daily. In this case the mean value of 144 kilometres per day is probably a safer one to use. If the point where the course of the Takazze turns from north to west be taken as the centre of its basin, then the water from this point has about 450 kilometres to travel to Khashm el Girba, and 425 kilometres more to the Nile. In doing so it falls from about 900 metres above sea-level at this point of the Takazze to about 460 metres at Khashm el Girba, and then to about 350 metres at the Nile. Thus, if it takes 2·75 days from Khashm el Girba to the Nile, we may add about 2·5 days for the

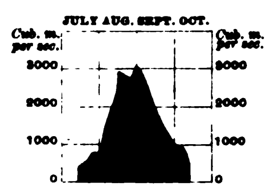
GAUGE READINGS AND MEAN DEPTH OF ATBARA RIVER

Fig. 1. Abu Dar (R. Atbara)



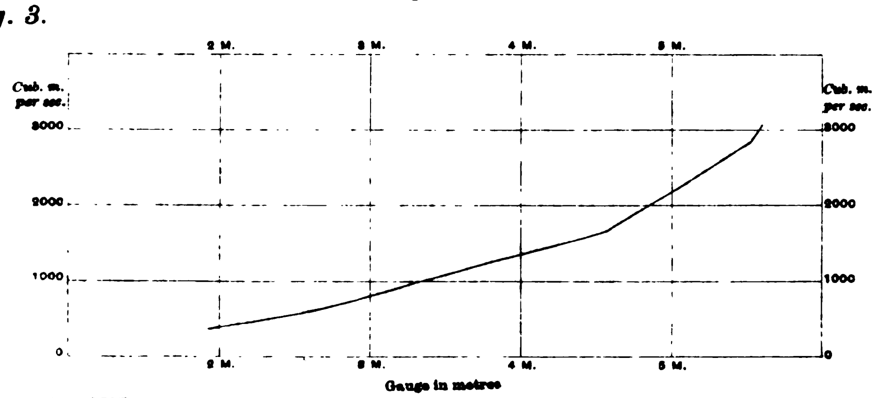
Discharge Diagram 1903

Fig. 2



Discharge Curve 1903

Fig. 3.



SURVEY DEPT.

rainfall of the middle of the upper catchment basin to reach Khashm el Girba which will give 5 to 5·5 days for it to reach the Nile.

It is instructive to compare the gauge-curve of Khashm el Girba, representing the drainage of the northern part of Abyssinia with that of Roseires, representing the drainage of the central and southern part. After June most of the larger rises and falls of the Roseires gauge can be matched by others about the same date on the Khashm el Girba gauge, those of July 30, August 3, August 10-18, August 27-31, September 17-23, 1903, being the most marked. This shows that the rainfall is widely distributed and varies not locally so much as by a succession of heavier and lighter falls which affect the whole plateau similarly.

It is noticeable that the mean date for the highest gauge-reading is two days earlier for Khartoum than for Aswan, and if corresponding years are taken from the two tables, it will be found that the date of the highest gauge-reading at Aswan often precedesthat of Khartoum, sometimes by as much as twenty days (1880 and 1881). This is due to the Atbara river, which, being in highest flood soon after the middle of August, may with the increasing Blue Nile flood, cause a higher reading at Aswan than their combined waters at the time when the Blue Nile is at its maximum and the Atbara has fallen. The Atbara drains a part of Abyssinia to the north of the basin of the Abai or Blue Nile, and the rains in the northern basin decrease earlier than those of the more southern districts of Gojam and Wallega.

The Mareb River or Khor el Gash.—The Mareb river, known lower down as the Gash or Khor el Gash, has much in common with the Atbara; fed by similar rains, draining a plateau through a deep ravine eroded by its waters, and on leaving the Abyssinian plateau turning sharply to the north it differs from it only in size but this very difference prevents the Gash from being able to carry its waters across the plains of the Sudan either to the Atbara or the Nile.

It rises a little south-west of Asmara in Eritrea, near the hill of Tacara at an altitude of about 2000 metres; flowing at first in south-easterly direction then south and south-west as far as its junction with the Belesa river which rises near Adigrat, it then turns to the west and then later on to the north-west.

It drains the northern part of Abyssinia and a small portion of southern Eritrea and carries the run-off of this area as far as Kassala, a distance of about 535 kilometres from its source.

In the upper reaches there is always water but it is not flowing in the dry season; large pools occur bounded by rocky sills and when the rains begin the surface of the water connecting them rises from below the surface to above it, and running water again appears.

The rainfall of Addi Ugri, Keren and Chenafena (see p. 208) fairly represents the rainfall which feeds it. This may differ somewhat from that of the Abyssinian table-land to the south of it, as in 1905 when in Eritrea the rainfall was above the average although to the southward there was a large deficiency.

At Kassala meteorological observations have been made from 1901 besides some in 1894 and 1895.

These are summarized in the following tables :—

TEMPERATURE CENTIGRADE 1901-1904.

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Mean	21·0	23·2	26·6	30·3	32·0	30·4	27·7	27·4	29·3	29·5	28·4	23·0	..
Mean Maximum.	32·1	34·4	37·8	40·0	40·7	39·1	35·6	34·0	36·7	37·7	36·9	35·0	..
Mean Minimum.	15·3	17·5	19·4	22·5	25·9	25·3	23·3	23·0	23·2	23·8	21·6	17·2	..
Extreme Max. ..	34·9	39·3	40·9	43·6	43·3	42·1	38·5	37·7	39·7	40·3	38·9	37·8	..
Extreme Min. ..	10·3	13·2	13·7	17·1	22·1	21·4	20·6	19·8	19·8	20·3	16·6	12·2	..
Range..	16·8	16·5	18·5	17·5	14·8	13·8	12·3	11·0	13·4	14·1	15·4	17·8	..

RAINFALL IN MILLIMETRES.

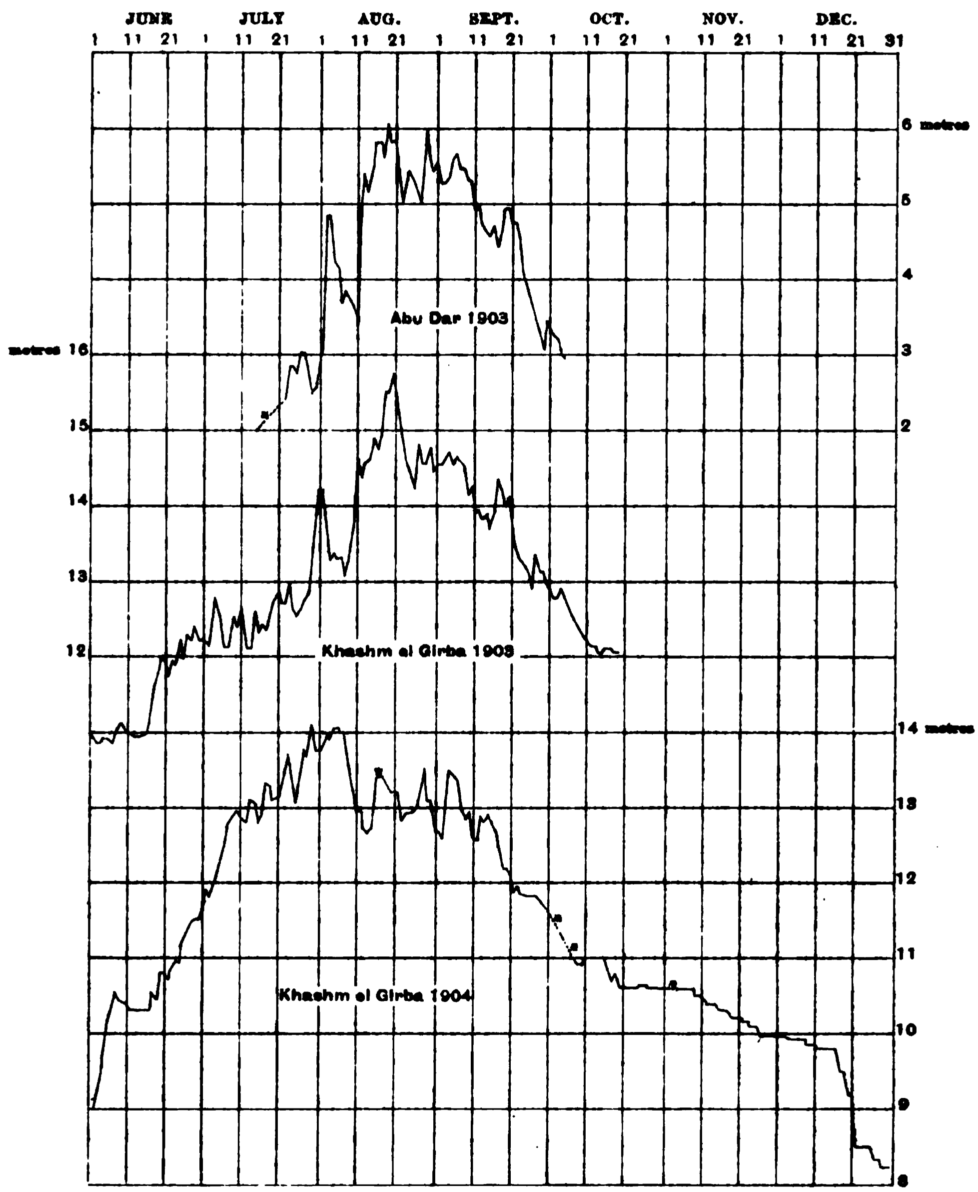
YEARS	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1894 ..	..	..	..	..	..	..	..	..	..	..	0	0	[0]
1895 ..	0	0	0	0	3	9	..	..	..	..	..	..	[12]
1900 ..	..	..	..	..	..	..	..	230	27	..	0	0	[257]
1901 ..	0	0	0	2	6	72	37	101	31	0	0	0	249
1902 ..	0	0	0	6	1	3	96	50	20	25	0	0	201
1903 ..	0	0	0	2	24	23	63	78	76	0	0	0	266
1904 ..	0	0	0	0	4	6	58	62	127	59	4	0	320
1905 ..	0	0	0	0	2	30	93	127	126	0	0	0	378
Mean..	0	0	0	2	7	24	69	108	68	17	1	0	296

Menges[1] visited the Mareb in April 1881 where it turns westward at a point in lat. 14°.45 N. and almost on the 38th meridian; the channel was here 30 metres wide but without water in the dry season although it was obtainable by digging to a depth of less than a metre.

[1] Pet. Mitt. 1884, p. 162, see also Munzinger "Ostafrikanische Studien," 1864.

PLATE XXXI.

GAUGE READINGS RIVER ATBARA 1903 & 1904



x Observations missing

Survey Dept. Cairo.

The Blue Nile from a basin of considerable size receives enough water to keep the water-table above the floor of its bed in the dry season while in flood its discharge may reach perhaps 12,000 cubic metres per second and its load of sediment can be carried down to Egypt without being deposited to any considerable extent. The Atbara carrying a heavier load, draining a smaller basin, one of lighter rainfall and with a shorter rainy season, can only keep its water table above its bed for some 6 months in the year but during that time and especially in its flood period it is able to carry its load to the Nile and there to add it to that which the Blue Nile has brought down.

The Gash has a still smaller basin and rising further north has both a lighter rainfall and a shorter rainy season besides flowing out on to plains which lie near the limits of the region receiving an appreciable rainfall.

Summary.— One of the two principal factors in the Nile supply, which has been already mentioned is the Albert lake and the rainfall on the plateau immediately north of it; the other, and by far the more important, is the rainfall on the Abyssinian tableland which supplies the Blue Nile and the Atbara. From these pours down the annual Nile flood in July, August, September, and October, while in most years the Blue Nile flows throughout the year, though its volume after January is small. We have seen that the punctual arrival of the flood each year is due to the regular northward movement of the rainbelt, and that the regularity of the rise and fall is caused by the long distance its waters traverse before reaching Egypt, whereby the irregular rises and falls of the upper reaches are smoothed out. Being supplied from a single river system with a single rainy season, excessive floods are not caused by floods in different large tributaries occurring at the same time, but the Nile flood varies very nearly as the rainfall on a single area of no very great extent and consequently within moderate limits. This rainfall decreases from south to north, and while it maintains the Sobat at a high level from July to December with the aid of the flooded plains of the Pibor, the Blue Nile is falling rapidly in October, and the Atbara after January is from Khashm el Girba downwards only a succession of pools. Abyssinia after centuries of arrested development appears now to be advancing rapidly, and with the cessation of the civil war which was almost continuous up to about fifty years ago, a large increase of the population must take place. While it is not likely that any change of river regimen will occur in the immediate future, it is impossible

A few days later he reached it at Todluk about 140 kilometres lower down where the channel was 150 to 350 metres wide.

At Kassala the channel is 150 metres wide and the river in flood flows here 1 metre deep, but in unusually wet years a considerably larger area is likely to be inundated.[1] Beyond this, ill-defined scour channels occur and these finally combine to form two or three main channels which are usually shown in maps as extensions of Gash which flow to the Atbara, though in fact only in the very wettest year would any water be carried by them even near to the Atbara. On the alluvial fan at Kassala where the flood waters of the Gash finally lose themselves water can be obtained always at a depth of 6-7 metres in spite of the small volume discharged, which is estimated to be about 100 cubic metres per second.[1]

The Gash flows usually about 80 days in the year, coming down early in July and drying up the latter part of September, its bed being dry for the remainder of the year, but during this flood period it runs constantly, rising and falling irregularly as the tributaries in its upper course pour in their contributions. The way in which the Gash spreads out in the neighbourhood of Kassala and deposits its load in the form of an alluvial fan is typical of rivers of a certain class. When rivers already loaded with sediment emerge from their mountain valleys of high slope on to a level plain under arid climatic conditions where the water-table is at some distance from the surface their water sinks in almost at once instead of flowing on the surface and therefore deposits its load of sediment as an alluvial fan. This fan is built up most rapidly at its head and as the floods of successive years come down new temporary channels are formed which divide and reunite, forming a network of channels, each by deposit building up banks for itself which are probably cut through in the next season, of the summer rainfall; consequently the very moderate volume which it supplies is unable to carry forward its load but forms an alluvial fan. This action is typically shown in the High Plateaux of North America and probably many of the streams leaving the Beni Shangul hills and flowing westwards have similar characteristics.

We have therefore in the Blue Nile the Atbara and the Gash three sets of conditions, the same in kind but differing in degree. All receive their water supply from the heavy summer rainfall of the Abyssinian tableland, flow through deeply cut valleys and open on to the level Sudan plains where they receive but a small additional supply.

[1] Dupuis loc. cit. p. 32 ff.

CHAPTER VII.

The Nile from Khartoum to Aswan.

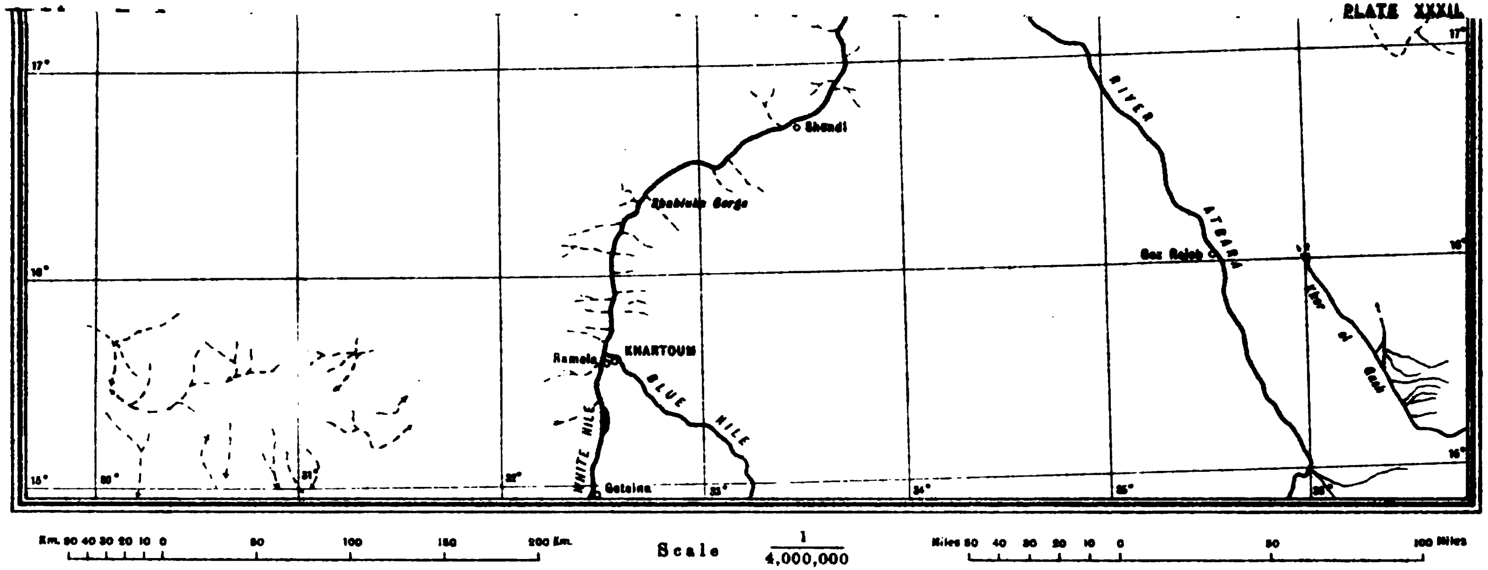
General description.—From Khartoum to Aswan, a distance of 1875 kilometres, the Nile flows through a desert region, and cultivation along its banks is restricted to isolated patches which only here and there are sufficiently close to form a belt of vegetation of any length.

The rainfall, which at Khartoum is only 107 mm. a year on the average, rapidly decreases northwards and at Berber two or three rainstorms are the most that occur, while as far as Merowe they happen occasionally; beyond this point the slightest shower is rare. A new climatic province has been entered, characterised by arid conditions and vegetation is limited to the banks of the river, away from which there are but a few thorny acacias and other hardy desert plants which exist in the shallow drainage lines or wadies. Except for the volume added by the Atbara the Nile is rapidly losing water by evaporation and seepage throughout this portion of its course and though observations are as yet insufficient to determine the amount, still it must be considerable. Southerly winds just reach lat. 18° N. and north of this the northerly trade winds, which blow throughout the year, from their dryness cause rapid evaporation.

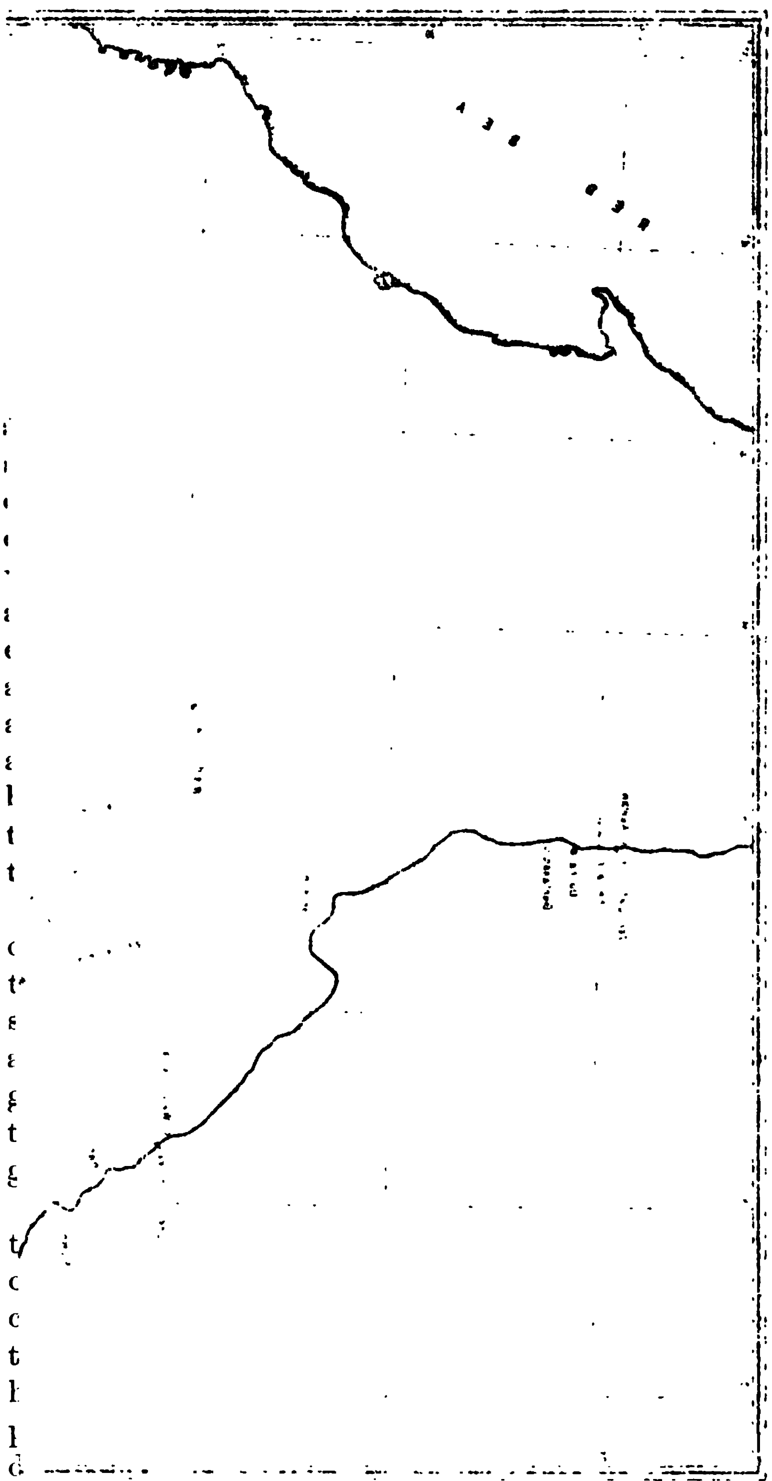
Right and left of the river the country rises gradually but reaches only very moderate altitudes; 820 metres or about 500 metres above the river is the highest point in the Bayuda desert, while on the Berber side it is nearly halfway to Suakin before hills rising to 1200 metres are met with. The desert to the east of Dongola and Wadi Halfa is generally from 400 to 600 metres above sea level while a few hills rise to 1000 and 1200 metres; to the west the desert is flatter and the general altitude rarely exceeds 500 metres.

There has not as yet been any very systematic geological examination of this part of the desert. In general there is a series of crystalline rocks represented by gneiss, granite, and schists, while in certain places there is a large development of hornblendic rocks. On this highly eroded old land surface the beds of the Nubian sandstone have been laid down, without, so far as is known at present, any older pre-cretaceous rocks occurring. It may be that a conglomerate largely developed at Jebel Reft near the Murrat Wells between Korosko and Abu Hamed, may represent some of these and it is too soon to say

PLATE XXXII.



17°
16°
15°
30°
31°
32°
33°
34°
35°
36°
Shendi
Shabluka Gorge
KHARTOUM
Ramela
BLUE NILE
WHITE NILE
Geteina
RIVER ATBARA
Goz Rajeb
Khor el Gash
Km. 50 40 30 20 10 0 50 100 150 200 Km.
Scale 1/4,000,000
Miles 50 40 30 20 10 0 50 100 Miles



definitely that others do not exist. Much examination of all this district remains to be done, and it will not be until the geographical conditions and the recent geographical development of this part has been carefully studied on the spot that we may hope to trace the causes which have determined the great curve of the river between Abu Hamed and Dongola.

In the reach from Khartoum to Aswan the Nile attains its greatest volume as here are collected the waters of the Blue and White Niles and the Atbara, while evaporation and absorption have not yet materially diminished them. For a few days only at lowest stage in dry years when the Blue Nile is supplying almost nothing, the point where there is the maximum volume in the river is perhaps immediately below the Sobat mouth.

We have seen that the Blue Nile and the Atbara in their upper reaches have eroded their valleys through the overlying basalt and sandstone until they now flow through channels cut in the older granite, gneiss, etc. representing the old land surface on which the sandstone was laid down. On reaching the Sudan plains they have cut their way through the alluvial deposit which has been laid down in earlier periods on the rock which now underlies it. This is mostly the sandstone which was in its turn deposited on an older surface of crystalline granite, gneiss and other rocks, which began as a high ridge to the east of the present Nile valley and sloped westwards. But this surface had already been greatly eroded so that ridges rose up in some places while more deeply worn depressions occurred at others. When now the Nile had cut its way through the overlying sandstone without much difficulty, it met at certain points ridges of harder crystalline rocks, which offered much greater resistance to erosion and therefore delayed the grading of the reach of the river up-stream of it, causing a short length with a comparatively steep slope to intervene between two of gentler slope. These old ridges which have given rise to the so-called Nile Cataracts are composed of various rocks, often intersected by faults, cleavage planes, or dykes, which form lines of weakness along which the water soon eats out narrow channels. Thus the position of the ridges of the crystalline rocks determines the occurrence of cataracts while the structure of the rocks determines the position of the channels in the cataracts.

Climate.—As a gathering ground this part of the Nile Basin is wholly ineffective, for the occasional storms which burst on the desert very rarely reach the Nile, and the volume carried to it on these occa-

sions is insignificant, so that after the accession of the Atbara supply there is a steady diminution in the volume owing to the climatic conditions of the area which are represented in the following tables:

Mean temperature—°C.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Khartoum	21·0	23·8	26·6	30·5	33·2	32·9	31·4	31·3	31·1	31·3	27·3	23·1	28·6
Berber ..	19·7	21·8	25·4	29·3	33·8	34·2	33·1	33·6	32·6	29·8	25·3	21·1	28·3
Merowe ..	..	..	..	27·4	31·9	35·0	33·7	34·3	32·4	31·3	27·2	20·3	..
Wadi Halfa	15·0	17·2	21·9	26·4	30·5	32·2	32·0	31·7	30·3	27·6	21·3	17·1	25·3
Aswan ..	14·5	18·5	21·4	26·1	30·0	32·4	32·7	32·4	30·3	27·9	21·7	17·0	25·4

Mean maximum temperature.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Khartoum	26·4	32·4	36·1	39·6	42·0	41·7	38·5	37·9	39·2	39·0	35·8	32·0	36·7
Berber ..	30·4	32·1	36·2	39·9	43·6	44·5	42·5	43·4	42·5	39·9	35·4	33·2	38·6
Merowe ..	..	..	..	36·6	40·6	43·3	41·2	41·5	39·8	38·8	34·7	28·1	..
Wadi Halfa	23·3	26·6	32·4	36·0	39·7	41·4	40·8	40·0	38·5	36·2	29·7	25·8	34·2
Aswan ..	22·9	28·0	31·1	36·2	39·1	41·4	41·5	41·9	39·7	38·8	31·7	27·3	35·0

Mean minimum temperature.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Khartoum	14·8	17·4	18·6	21·8	25·3	25·8	24·9	24·7	24·6	23·6	20·5	16·5	21·4
Berber ..	9·3	13·5	18·2	20·4	25·6	26·4	26·3	29·2	27·0	23·4	19·1	14·7	21·1
Merowe ..	..	..	..	19·0	24·2	27·0	26·5	27·9	25·9	25·3	20·9	13·6	..
Wadi Halfa	9·0	9·8	13·2	17·5	21·9	23·6	23·4	23·9	23·0	20·4	14·6	10·9	17·6
Aswan ..	9·0	11·5	13·8	18·4	22·0	24·2	24·7	25·0	23·0	20·7	15·3	11·4	18·2

Mean range (maximum-minimum).

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year.
Khartoum	11·6	15·0	17·5	17·8	16·7	15·9	13·6	13·2	14·6	15·4	15·3	15·5	15·2
Berber ..	20·1	18·6	18·0	19·5	18·0	18·1	16·2	14·2	15·5	16·5	14·5	18·5	17·6
Merowe ..	..	..	..	17·6	16·4	16·3	14·7	13·6	13·9	13·3	13·8	14·5	..
Wadi Halfa	14·3	16·8	20·2	18·5	17·8	17·8	17·4	16·1	15·5	15·8	15·1	14·9	16·7
Aswan ..	13·9	16·5	17·3	17·8	17·1	17·2	16·8	16·9	16·7	18·1	16·4	15·9	16·7

Mean maximum extreme.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Khartoum	36·0	39·2	39·6	44·4	44·4	44·7	42·3	41·5	42·6	41·8	39·9	36·0	41·0
Berber ..	35·8	38·5	42·0	45·3	46·2	46·7	44·8	46·0	44·8	42·8	40·2	35·7	42·4
Merowe ..	..	..	..	42·2	45·0	46·0	42·5	44·5	42·5	43·0	37·5	37·0	..
Wadi Halfa	31·0	35·6	40·4	44·2	45·7	46·5	44·1	43·9	42·9	42·4	36·5	32·6	40·5
Aswan ..	29·2	33·9	39·7	44·9	45·1	44·6	45·2	44·3	42·2	41·5	38·2	32·8	40·1

Mean minimum extreme.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Khartoum	9·2	12·4	13·3	16·7	19·1	21·4	21·1	20·2	20·9	19·0	16·1	11·2	16·1
Berber ..	3·0	4·0	11·0	16·0	19·2	21·8	21·5	23·0	23·8	20·0	13·8	8·0	15·4
Merowe ..	..	..	..	14·0	18·0	23·0	24·0	25·5	22·5	17·0	14·0	5·5	..
Wadi Halfa	4·0	4·8	8·3	11·2	16·5	19·5	19·8	20·3	18·9	15·9	9·5	4·9	12·8
Aswan ..	4·9	7·3	9·2	13·9	17·6	20·5	21·9	21·5	19·1	16·4	8·8	4·3	13·8

Mean relative humidity.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Khartoum..	28	26	17	15	22	32	46	50	43	31	29	30	31
Berber. ..	48	40	25	14	19	18	29	24	27	30	34	30	29
Merowe [1] ..	..	..	..	14	14	14	18	22	26	24	30	33	..
Wadi Halfa [2]	45	38	32	24	19	21	27	32	32	36	43	46	33
Aswan ..	51	37	32	30	25	24	22	25	30	35	44	50	34

[1] 8 a.m.
[2] $\frac{9 \text{ a.m.} + 9 \text{ p.m.}}{2}$ from 1890-1900, $\frac{8 \text{ a.m.} + 8 \text{ p.m.}}{2}$ 1901 to 1904.

Vapour tension in millimetres.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Khartoum	5·4	5·4	4·6	5·1	8·2	11·0	13·7	15·3	13·7	9·7	7·1	6·5	8·8
Berber ..	8·7	7·3	6·2	4·4	7·7	6·8	10·3	8·8	9·7	9·0	8·0	7·0	7·8
Merowe ..	..	..	..	3·47	5·08	4·94	6·82	8·00	8·42	6·11	7·17	5·69	..
Wadi Halfa	5·7	5·4	5·9	6·2	6·5	7·6	9·6	11·1	10·2	9·9	8·1	7·3	7·7
Aswan ..	5·9	5·3	5·6	7·4	7·8	8·4	7·8	8·0	9·1	9·5	8·0	6·6	8·1

Mean Relative Humidity at 2 p.m.

	Jan.	Feb.	Mar	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Khartoum	20	16	12	12	15	20	28	30	26	19	17	21	20
Merowe .	..	..	..	5	5	7	9	9	13	12	18	19	..
Aswan ..	30	22	17	17	15	15	13	13	18	22	25	30	20

Periods covered by the foregoing tables.

Khartoum	July 1900-Dec. 1904.
Berber	March 1902-Dec. 1904 (minimum for 1903 rejected).
Merowe	April to December 1905.
Wadi Halfa	February 1890 to December 1904.
Aswan	January 1901 to December 1904.

Wadi Halfa.— Percentage frequency of winds 1891-1900.

	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm	Mean direction
January ..	42·2	17·9	..	1·3	..	..	6·3	32·0	..	N. 11° W.
February ..	35·2	13·8	..	..	..	0·4	11 5	48·9	0·4	N. 24° W.
March	18·3	16·0	..	1·3	..	5·4	2·8	49·7	7·1	N. 24° W.
April	27·1	7·4	2·0	0·7	3·7	..	2·8	47·3	8·5	N. 22° W.
May	14·1	19·9	1·9	2·2	1·3	4·5	2·1	46·4	7·3	N. 19° W.
June	17·8	16·3	0·3	1·9	1·3	4·7	3·6	48·1	5·6	N. 25° W.
July	9·9	14·7	..	2·3	0·3	5·5	7·0	59·1	0·9	N. 36° W.
August ..	3·4	18·5	0·3	2·0	2·6	6·5	3·4	61·8	1·6	N. 36° W.
September ..	17·5	11·5	..	1·7	..	..	..	67·6	1·7	N. 26° W.
October ..	21·1	15·9	1·2	0·9	0·9	2·5	0·3	51·6	5·5	N. 19° W.
November ..	31·0	14·8	..	..	..	1·7	1·0	50·5	1·0	N. 17° W.
December ..	30·6	5·3	1·1	..	..	..	..	48·8	13·6	N. 20° W.
Year	22·3	14·3	0·6	1·2	0·8	2·6	3·5	51·0	4·4	

Merowe.— Percentage frequency of winds 1905.

1905	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm	Mean direction
April	33	56	..	..	..	..	1	10	..	N. 18° E
May	26	39	2	7	11	5	4	6	..	N. 26° E
June . ..	11	55	6	3	3	9	4	9	..	N. 33° E
July	15	33	2	3	2	15	7	23	..	N. 12° W
August ..	23	38	..	7	2	16	1	13	..	N. 11° E
September ..	19	32	2	6	1	10	2	28	..	N
October. ..	13	66	3	3	..	2	2	11	..	N. 30° E
November ..	17	70	1	..	..	2	..	10	..	N. 30° E
December ..	22	73	..	..	..	1	..	4	..	N. 32° E

Berber.—PERCENTAGE FREQUENCY OF WINDS MARCH 1902 - DECEMBER 1904.

	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm	Mean direction
January ..	75	..	1	..	..	..	6	18	..	N. 12° W
February ..	70	2	1	..	..	..	5	22	..	N. 12° W
March	68	12	3	..	..	..	4	13	..	N. 1° W
April	60	10	8	1	2	..	3	15	..	N. 1° W
May	44	8	12	4	17	3	8	5	..	N. 12° E
June	48	7	5	4	13	3	16	6	..	N. 13° W
July	30	2	4	1	18	12	28	..	..	N. 82° W
August ..	32	4	5	2	16	9	24	9	..	N. 75° W
September ..	28	6	10	4	23	7	13	9	..	N. 45° W
October ..	46	10	21	4	7	2	4	6	..	N. 25° E
November ..	57	7	8	..	..	..	11	18	..	N. 8° W
December ..	78	3	1	..	..	..	6	..	..	N. 7° W

Evaporation.—In this reach of the river evaporation is at a maximum and it will therefore be convenient to collect together such data as exist which bear on the loss of water from this cause. Evaporation depends upon the temperature of the water surface, the humidity of the air, the rate of air movement over the water surface and lastly upon the atmospheric pressure. Thus it is evident that values of the depth of water evaporated daily, which have been obtained under a certain set of conditions, cannot apply to other situations where the conditions are different. In meteorology the object aimed at is to obtain results at different places which shall be comparable with one another, in order that the part played by evaporation in the climate of the region may be understood. For this purpose a single pattern of evaporimeter is used, which is exposed as nearly as possible in the same way at each station, but the results obtained represent the loss by evaporation from a small free water surface exposed under these special conditions, and the resulting value cannot be applied to larger surfaces under different conditions without due precautions, as it will probably require correction. In Egypt the Wild evaporimeter has been used for some time, and data are available

from Alexandria, Port-Said, Abbassia, Helwan, Assiut and Aswan, which are given in the following table.

MEAN DAILY EVAPORATION AS MEASURED BY A WILD EVAPORIMETER IN A THERMOMETER SCREEN.

Months	Alexandria				Port-Said						Abbassia		
	1901	1902	1903	1904	1900	1901	1902	1903	1904	1905	1901	1902	1903
January	5·1	4·5	4·8	6·6	..	1·6	[1·7]	1·4	2·4	2·0	..	1·1	1·2
February	5·0	5·3	5·2	6·5	..	1·7	1·8	1·5	2·1	2·5	.	2·1	1·4
March	5·4	5·3	6·1	7·6	..	2·9	2 6	1·6	3·4	2·7	..	3·2	2·4
April	5·2	6·0	8·2	7·2	.	2·8	2·4	1·9	2·8	3·1	5·7	5·0	4·4
May	5·7	7·2	8·0	7·1	.	3·0	3·5	2·3	2·8	3 0	5·7	8·1	6·4
June	5·6	7·5	7·6	7·4	2·3	2·4	2·2	2·1	2·9	3·3	6·0	6·4	6·8
July	7·4	7·8	7·3	7·5	2·5	3·0	2·5	2·1	3·2	3·1	5·8	5·2	5·7
August	7·1	7·7	7 6	7·6	2·8	3·1	2·2	2 2	3·6	2·7	·5·4	5·7	5·5
September ...	7·0	7 8	8·2	7·4	2·5	2·6	2·1	2·2	2·7	2·7	3·7	4·3	4·4
October	6·5	8·0	7·6	6·8	2·0	2·5	1·8	1·8	3·4	3·0	3·7	4·5	3·8
November... ...	5·6	7·0	6·5	6·6	2·0	2·1	2·0	2·7	2·5	2·3	2·2	2·5	2·4
December... ...	6·9	5·9	5·6	4·4	1·8	1·3	1·7	2·0	1·6	2·2	1·6	1·8	1·7
Mean...	5·97	6·67	6·89	6·89	[2·27]	2·42	[2·21]	1·98	2·78	2·7	[4·42]	4·1·	3·34

Months	Assiut						Aswan					Helwan observatory
	1900	1901	1902	1903	1904	1905	1901	1902	1903	1904	1905	1904
January ...	..	2·6	3·1	[2·7]	2·3	2·0	[4·8]	[5·2]	[4·5]	5·7	5·1	3·2
February ...	.	4·2	4·3	3·6	3·1	2·5	[7·6]	[7·8]	[5·0]	7·2	7·2	4·4
March ...	..	7·0	7·0	[5·5]	4·1	5·2	[10·9]	[10·5]	7·7	8·4	6·3	6·1
April... ...	..	9·7	9·6	[8·7]	6·0	6·0	[11·8]	[10·6]	10·2	11·4	10·9	9·2
May	..	10·7	14·1	11·3	8·6	9·8	[14·3]	15·7	[11·9]	[13·2]	12·6	10·6
June	..	14 4	15·5	[12 2]	10·8	12·1	[16·8]	15·2	13·2	15·3	17·1	12·7
July	..	16·1	12·5	11·4	10·0	11·2	15·2	13·2	13 1	14·9	14·0	10·8
August ...	11·7	14·3	12·9	[9·7]	10·1	9·4	[14·8]	[13·2]	12·3	12·1	17·7	9·2
September	9·3	9·4	9·4	7·0	8·7	6·0	[15·2]	12·0	10·7	10·8	11·4	9·1
October ...	6·1	5·6	6·9	4·3	6·1	4·9	12·6	8·8	9·2	8·6	10·0	8·9
November	4·2	3·6	4·4	2·2	2·5	2·6	10 2	5·7	6·1	5·6	7·6	3·8
December	2·9	2·9	3·0	[2·0]	[1·8]	1·8	[6·3]	[4·1]	4·8	4·1	4·6	3 6
Mean ...	[5·84]	8·38	8·60	[6·72]	[6·18]	6·1	[11·71]	[10·17]	[9·06]	[9·78]	10·4	7·80

In Upper Egypt evaporation has been taken as 7·5 mm. per day in summer[1] and 3 mm. per day in Lower Egypt, or 5 mm. and 2 mm. per day as the mean values for the year ; 8 mm. is given as a mean value for the year[2] while 1·2 mm. is also given as the average amount lost by a canal by evaporation and absorption,[3] and 8 mm. is taken as the probable mean daily loss from the surface of the Aswan reservoir[4]. It seems very doubtful whether such different conditions really give any close agreement. The value of 7·5 mm. was obtained from observations

[1] Willcocks, "Egyptian Irrigation," London 1899, p. 14.
[2] Ibid. Table viii., p. 50.
[3] Ibid. p. 65.
[4] Ibid. p. 438.

on lake Qurun in the Fayum[1] which fell 0·40 metres in 60 days (May and June 1887) while canals supplied 330,000 cubic metres daily in May and 210,000 in June, thus giving a daily loss of 7·5 mm. over the lake surface which is taken as 307 square kilometres; but this area is certainly too large as the area of the lake today is only about 233 square kilometres and it has not reduced in area by anything like 23% within 9 years. If the lake be taken at 233 square kilometres the deduced value for evaporation will be 10 mm. The value for Lower Egypt is derived from the fact that a lake of 380 square kilometres at sea level received for 120 days two million cubic metres of water per day and at the end of the period had risen 0·25 metre. But such data give but little information for determining the loss from river or canal surfaces except to indicate that the value for these latter is certainly higher. Air passing over a large water surface such as those above referred to takes up a considerable amount of water vapour at first but its capacity for doing so is thus reduced and from the leeward portion of the lake evaporation is very markedly less than on the windward side. At Bombay the annual evaporation from different areas diminished largely as the area increased:

1 square foot	10,000 sq. feet	lakes[2]
217 cm.	193 cm.	150 cm.

Mazelle has shown that salt (sea) water the rate of evaporation is one-tenth less than on fresh water and this will apply to some extent to the Qurun lake where the water is strongly brackish. It is therefore probable that the loss from canals and river surfaces in Egypt is considerably higher than 7 mm. per day in summer but no careful determinations have been made.

Recently the results of the Wild pattern evaporimeter exposed in a meteorological screen have been compared with the evaporation from a surface of 16 square metres freely exposed to sun and wind, the measuring pan being placed in the centre of a tank of water 4 metres square.

As a result of observations extending over 161 days from April to October this open exposure showed a rate of evaporation which was 38 per cent more than was given by a Wild pattern instrument exposed in a screen, where the wind velocity is greatly reduced by the louvred sides of the screen, open however towards the north. The observations were made at Helwan Observatory which is situated on the desert plateau about 90 metres above the Nile and about 3 kilometres from the nearest cultivation.

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[1] Ibid. p. 438.

[2] Quart. Jour. R. Met. Soc., XX., p. 70

In his paper on the Aswan reservoir Fitzmaurice[1] considers the results of the Wild evaporimeter to be inaccurate but he appears not to have realised the effect of different conditions and takes the results of the normally exposed instrument as claiming to give the loss from a large reservoir surface. Still the form of evaporimeter used at the reservoir will not give wholly satisfactory results as it is a shallow tank 1 metre square and 0·3 metre deep exposed to the sun but somewhat sheltered from wind and protected by fine wire netting of which the side of each square is 2 mm.; this cannot be considered as reproducing the free exposure of the reservoir surface since evaporation increases as the square root of the wind velocity and a fine wire cover must greatly interfere with the free removal of water vapour.[2]

The following table gives a comparison between a Wild pattern evaporimeter exposed in a double-covered Renou screen and the open pan as used at the Aswan Reservoir. This pan was 1 metre square, 0·3 metre deep the top of its edges being level with the ground and the top covered with wire gauze 25 squares to the square centimetre. It was placed 80 metres to the north of the dam on the west bank of the river and was somewhat sheltered from the prevalent wind but exposed to the sun. The loss was measured daily; about $\frac{1}{3}$ to $\frac{1}{2}$ was allowed to evaporate and the box was then refilled.

MEAN DAILY EVAPORATION IN MILLIMETRES NEAR ASWAN RESERVOIR

	1903			1904			1905			Mean 1903-5		
	A	B	C	A	B	C	A	B	C	A	B	C
January	4·5	3·3	1·2	5·7	3·4	2·3	5·1	3·4	1·7	5·1	3·4	1·7
February	5·0	4·8	0·2	7·2	4·3	2·9	7·2	4·1	3·2	6·5	4·4	2·1
March..	7·7	6·0	1·7	8·4	5·9	2·5	6·3	6·2	0·1	7·5	6·0	1·3
April	10·2	9·7	0·5	17·4	7·0	4·4	10·9	7·6	3·3	10·8	8·1	2·7
May	11·9	11·0	0·9	11·2	8·4	4·8	12·6	9·2	3·4	12·6	9·5	3·1
June	13·2	11·5	1·7	15·3	9·2	6·1	17·1	9·8	7·3	15·2	10·2	5·0
July	13·1	11·9	1·2	14·9	9·4	5·5	14·0	9·7	4·3	14·0	10·3	3·7
August	12·3	10·8	1·5	12·1	9·5	2·6	13·7	9·2	4·2	12·7	9·8	2·9
September	10·7	7·5	3·2	10·8	7·5	3·3	11·4	8·0	3·4	11·0	7·7	3·3
October.	9·2	6·3	2·9	8·6	6·8	1·8	10·0	6·8	3·2	9·3	6·6	2·7
November	6·1	4·6	1·5	5·2	4·6	1·0	7·6	4·5	3·1	6·4	4·6	1·8
December	4·8	3·5	1·3	4·1	3·6	0·5	4·6	3·0	1·6	4·5	3·4	1·1
Year	9·1	7·6	1·5	9·8	6·6	3·2	10·4	6·8	3·6	9.8	7·0	2·8
%	100	84	16	100	67	33	100	65	35	100	72	28

A = evaporation as measured by Wild evaporimeter in screen.
B = evaporation as measured by 1 metre square pan in open.
C = A--B.

[1] Proc. Inst. Civ. Eng., 1903, vol CLII, p. 151.

[2] Recent experiments made at Helwan Observatory by Mr B. F. E. Keeling appear to show that evaporation from such a tank covered with this wire netting is about 30% less than from one without it.

It is hardly necessary to point out that these values of evaporation from a free water surface are not applicable to moist or wet land surfaces, still less to land carrying vegetation; here the conditions are greatly changed.

For each situation special determinations are required on account of its particular conditions. Eser[1] gives the following table which exemplifies this :

EVAPORATION IN GRAMMES FROM A SURFACE OF 1000 SQUARE CENTIMETRES.
Covered with:

	Fallow	Stones 1 cm.	Straw in centimetres. 0·5	2·5	5	Pine needles 5 cm.	Fir 5 cm.	Beech leaves 5 cm.	Growing vegetation grass etc.
1883 July 12 Aug. 12	5739	1862	2372	1040	571	621	878	630	13902
Percentage	100	33	42	18	10	11	15	11	243

If the surface layer is so thoroughly dried by a hot sun that capillary attraction no longer supplies water to the surface, as constantly happens in Egypt, evaporation decreases very greatly ; experiments have shown that such drying for 2 cm. reduces the evaporation to 34 % for quartz sand and 66 % for calcareous sand while with an 8 cm. layer it fell to 12 % and 16 % respectively.

Temperature of Nile water.—The temperature of the Nile water will also affect evaporation from it, and a considerable number of observations have been made which have been fully discussed by Guppy[2] and from them he deduces the following table:—

MONTH	BETWEEN ASWAN AND MINIA			BETWEEN FIRST AND SECOND CATARACTS		
	Air	Water	Water Diff.	Air	Water	Water Diff.
	C°	C°	C°	C°	C°	C°
January	14·8	15·9	+1·1	17·9	16·4	−1·5
February	16·7	16·9	+0·2	20·3	(18·3)	—2·0
March	19·8	20·2	+0·4	23·8	(21·4)	—2·4
April	22·8	21·4	−1·4	28·9	23·3	−5·6
May	27·2	23·3	−3·9	31·4	24·2	−7·2
June	28·9	24·2	−4 7	32·2	25·6	−6·6
July	30·2	25·8	−4·4	33·4	26·0	−7·4
August	29·9	26·5	−3·4	32·9	28·1	−4·8
September	28·2	26·1	−2·1	31·7	26·7	−5·0
October	26·4	24·8	−1·6	26·9	25·2	−1·7
November	20·7	20·3	−0·4	23·0	19·9	—3·1
December	17·7	18·3	+0·6	18·8	17·2	−1·6
Year	23·5	22·0	−1·5	26·8	22·7	−4·1

[1] Forsch., a. d. Gebiete der Agrikultur Physik, von Wollny 1881, p. 1.
[2] Roy Phys. Soc. Edin. 1894-5, p. 33.

To this may be added some observations made by Peel[1] between September 12 and October 23, 1851.

	CAIRO-ASWAN (11 DAYS)			ASWAN-KOROSKO (4 DAYS).			BERBER-KHARTOUM (4 DAYS).		
	Air	Water	Diff.	Air	Water	Diff.	Air	Water	Diff.
	C°	C°	C°	C°	C°	C°	C°	C°	C°
5.30 a.m....	25·1	24·9	−0·2	29·4	26·7	−2·7	21·7	25·9	+4·2
8 „ ...	26·3	25·0	−1·3	32·2	27·3	−4·9	..	..	..
12 noon ...	28·9	25·8	−3·1	35·4	27·8	−7·3	33·2	26 7	−6·5
6 p.m. ...	30·9	25·8	−5·1	36·1	27·9	−8·2	30·8	26·6	−4·2

At Hawamdia Sugar Factory, 17 kilometres above Cairo, the river temperature has been observed daily at 6 a.m. and 4 p.m. (6 p.m. from February 7-March 14), for some time by M. C. Roux the director of the factory[2] and they form a very instructive series.

Month	6 a.m.			4 p.m.		
	Air	Water	Diff.	Air	Water	Diff.
	C°	C°	C°	C°	C°	C°
February 1905	8·1	10·3	+2·2	15·7[3]	12·9	−2·8
March	11·3	16·1	+4·8	18·3[4] 23·0[5]	16·1 18.6	−2·2 −4·4
April	16·4	20·0	+3·6	29·2	21·8	−7·4
May	19·8	22·4	+2·6	34·0	24·4	−9·6
June „	22·5	25·7	+3·2	34·3	27·4	−6·9
July „	23·2	26·7	+3·5	35·1	28·1	−7·0
August „	23·2	26·8	+3·6	34·3	27·8	−6·5
September „	21·4	25·5	+4·1	30·8	26·5	−4·3
October „	20·0	25·0	+5·0	28·0	25·5	−2·5
November „	15·2	21·9	+6·7	23·5	21·9	−1·6
December „	9·0	16·8	+7·8	16·9	17·0	+0·1
January 1906	7·2	14·2	+7·0	16·8	14·8	−2·0

Seepage.—There is however another factor which is much more effective than evaporation in reducing the river supply. In humid climates the greater part of the rain which falls sinks into the ground

[1] A ride through the Nubian Desert, London 1852.
[2] I am indebted to the Société des Sucreries d'Égypte for these observations.
[3] At 6 p.m.
[4] 1-14 March 6 p.m
[5] 15-31 March 4 p.m.

and raises the water-table or upper surface of the saturated soil or rock mass. This surface is not a horizontal one but varies considerably according to the facility with which water can pass through the soil or rock, aud with the number of places at which wells, rivers or lakes draw off the water. Rivers and lakes therefore are almost wholly supplied by the seepage water from the water-table in the ground which is situated at a higher level. In arid countries such as Egypt and most of the Sudan, where rainfall is so slight as to be negligible, the water-table lies far below the surface and instead of being a source of supply to rivers flowing through them, it is the river which loses a considerable volume of water which percolates into the soil towards the water-table which is situated at a considerable depth. Only at lowest stage and close to the river may the water-table rise a little above the river level, and show itself by water trickling back into the river as occurs between Argin and Serra, about 20 kilometres north of Wadi Halfa, and at other places. The next stage is when the river does not supply enough water to keep the water-table as high as the river in its immediate neighbourhood; then the bed is dry though water may occur in isolated pools or may be obtained by digging. The Atbara represents this in the first half of the year before the rains begin in Abyssinia, as do many wadies throughout both Egypt and the Sudan.

Investigations are now in hand to determine the order of loss of water from this cause. From a certain number of measurements which have been made from time to time during the present low stage (1905-6), when the Atbara had ceased to supply it appears that the loss of water by seepage into the Nubian sandstone, where the river flows on the sandstone and not in an alluvial plain of fine deposited silt, amounts to approximately 120 cubic metres per second between Khartoum and Sarras at the beginning of February, 1906, or 10 % of the volume discharged, and 150 cubic metres per second between Sarras and Aswan when the reservoir is full. This amount decreases as the river falls and at lowest stage the water-table appears to return water to the river to a small extent.

Topography and geology.—Between Khartoum and Aswan the geological structure has most effect in the reaches of steeper slope which form the cataracts, while elsewhere its effect is less evident. It will therefore be more convenient to combine the topographical and geological descriptions.

The Blue Nile meets the White Nile at Khartoum at right angles and the combined stream now flows in a wide and comparatively shallow channel (Plates XXXIII and XXXIV*a*) with reduced velocity so that sand-banks are numerous. The rocks on either side of the valley are of sandstone and reach no great height. At 76 kilometres from Khartoum the river passes through the narrow gorge known as Shabluka and it is a point of some interest to determine why the river has cut its way through this hill mass of crystalline rocks which rises to about 120 metres above the plain which here is open and slopes gently towards the river. No detailed investigation of this spot has yet been made but the following account indicates the principal characteristics of this rock mass.

It is composed of an ancient group of volcanic rocks which have been penetrated by more recent dykes of felsite, while in the gorge itself these make up the main mass of the rock exposed. So far as a cursory examination showed, no special fracture or other line of weakness has determined the course taken by the river.[1] This would appear to indicate that the Nile has slowly cut its way into these crystalline rocks at a time before the surrounding country had been eroded to its present level.

Discharges were measured here from June to October 1903 at a point about 2 kilometres down-stream of Jebel Royan.[2] This gorge or cataract is given by Chélu[3] as falling 13 metres in a length of 18 kilometres; below this, where the velocity again moderates, sand-banks and islands are numerous. A survey of the Khartoum–Shabluka reach which has just been completed shows the water-slope (20 January 1906) to be 8·5 metres in 80 kilometres from Khartoum to the head of the gorge and only 0·24 metre in the 7·5 kilometres of the gorge itself.

At Shendi the river bends northwards, which direction it maintains until Abu Hamed, receiving on its way the Atbara, its last tributary, at a point 139 kilometres below Shendi and 40 kilometres above Berber. Here the alluvial plain deposited by the Atbara covers all the underlying rocks but at a short distance north of Berber crystalline rocks occur. About 45 kilometres down-stream of Berber is the beginning of the Fifth Cataract caused by these crystalline rocks, and another short length of rapids occurs about 40 kilometres further down-stream. Beyond this on reaching Abu Hamed, 208 kilometres from Berber, the river divides

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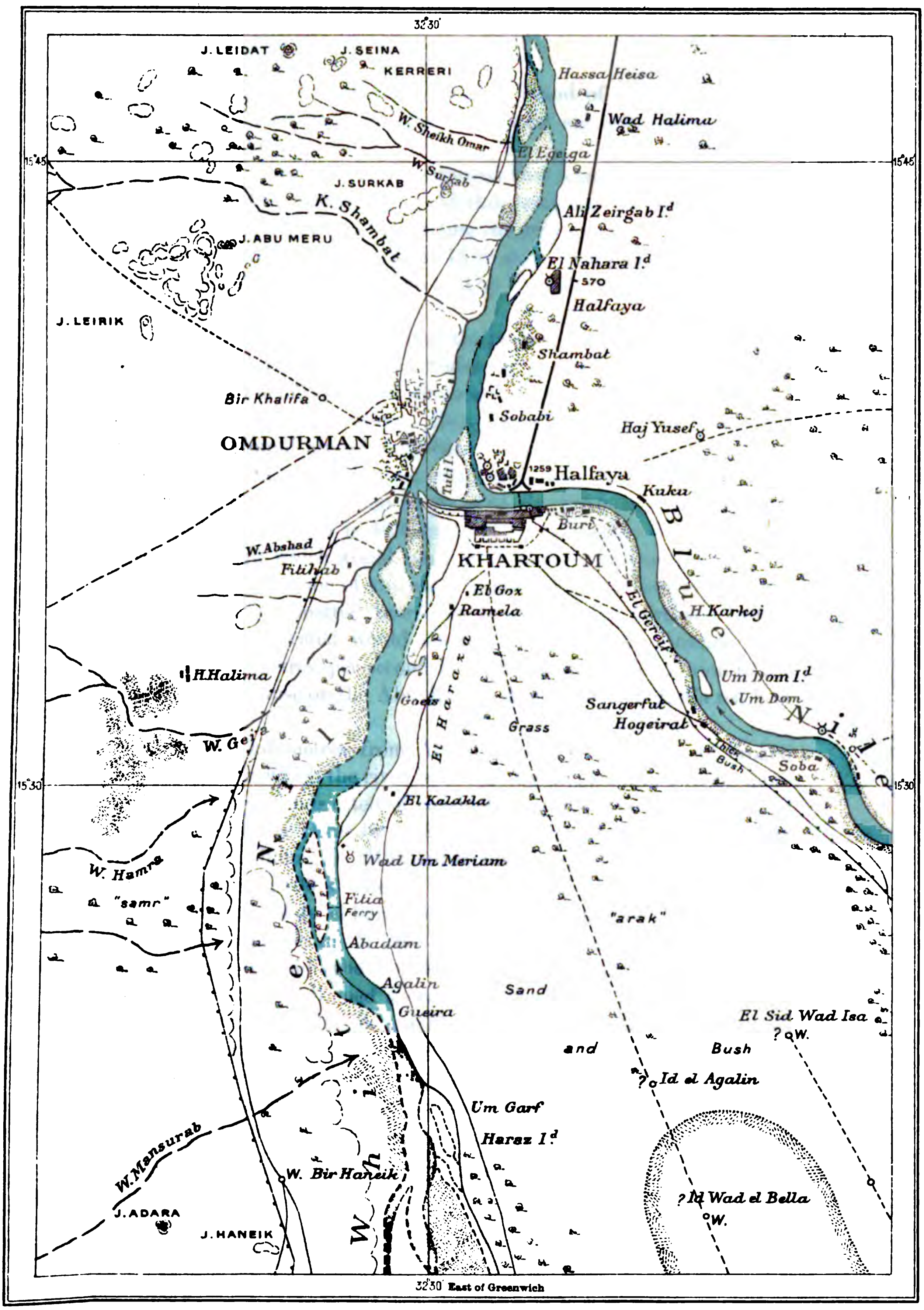
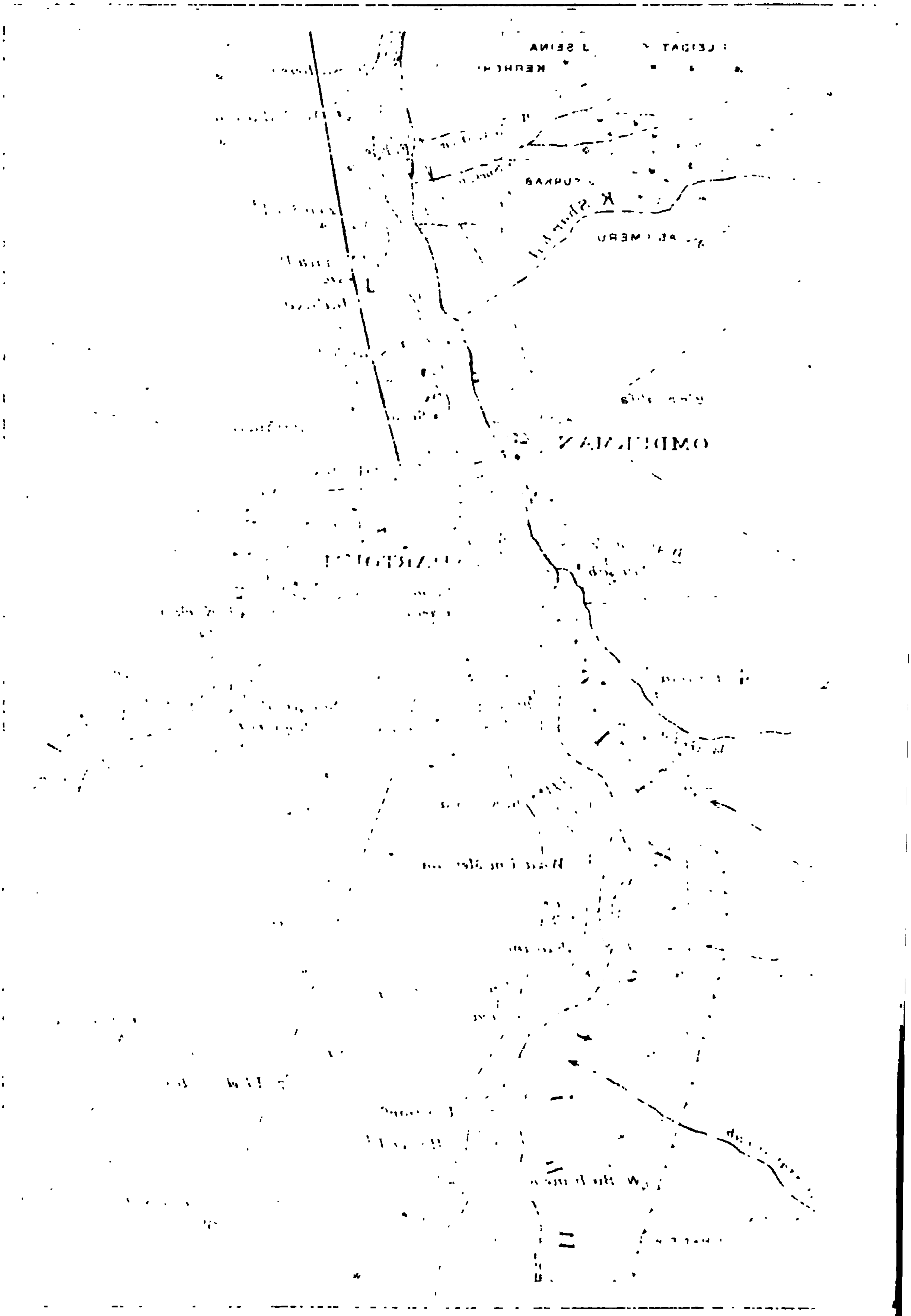
[1] Contributed by Dr. W. F. Hume F.G.S.
[2] See, p. 259.
[3] "Le Nil, le Soudan, l'Egypte." Paris 1891. p. 30.



SURVEY DEPT.

From I.D.W.O. Map No. 1489 Sheet 55 B.

Scale 1 : 250,000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J. SEINA

into two branches which include the large island of Mograt 30 kilometres long, and then bends sharply to the west and south-west towards Merowe and Dongola.

It has been more than once suggested that a canal should be made from this point to Korosko to avoid this bend and the three cataracts which lie in it. Malesieux[1] describing the principal public works which were being executed in Egypt in 1850 states that a line of levels had been carried across from Korosko to Abu Hamed under Mougel Bey in order to study the project.

In 1898 Abbate Pasha[2] revived the project and urged that it would be of benefit to that part of the Sudan as well as to Egypt though it appears far from offering such advantages as would compensate for the cost and difficulty of execution. He apparently believed that from Abu Hamed the ground almost immediately sloped northwards to the great Wadies Mandera and Gabgabba which carried a former drainage to the Nile where the Wadi Allagi meets it to the north of Korosko. But actually the watershed is 40 kilometres to the north of Abu Hamed forming a ridge which would have to be pierced, while at low stage of the river any reduction of the water passing Dongola and Wadi Halfa would be a serious matter ; moreover the evaporation from the surface of this proposed canal would amount at a moderate estimate to at least 10 cubic metres per second in the hot months, in addition to the loss from this cause on the Abu Hamed-Dongola-Wadi Halfa reach of the river.

About 100 kilometres from Abu Hamed a long stretch of broken water begins in which the river is constantly divided into two or more arms, by rocky islands often of considerable size. The rapids of Shirri islands, called Om Deras by Chélu, are the first and soon after follow the Kirbekan, Rahmi, El Mushani rapids and others ; the whole reach of the river from 100 kilometres downstream of Abu Hamed to a point a little upstream of Jebel Barkal and about 18 kilometres above Merowe, some 120 kilometres in all, has a considerable slope and in fact forms a single group of rapids, the so-called Fourth Cataract. Chélu makes the total fall from Abu Hamed about 50 metres giving for the distance of 240 kilometres from this place to Merowe an average slope of 1 in 4,800. The recent railway survey gives the difference in level of the water-surface at the end of June 1904, between Abu Hamed and Kareima as 67 metres in about 232 kilometres or about 1 in 3,500, which is certainly the more reliable.

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[1] "Annales des Ponts et Chaussées," Paris 1851, p. 180.
[2] "Le Canal Abbas."

From Merowe to Dongola, a distance of 270 kilometres, the river flows in a large curve free from rocky obstructions and with cultivated banks, while to the north of Dongola the alluvial plain widens to form the fertile island of Argo. Sixty-six kilometres north is the Hannek cataract, and here again the crystalline rocks, which since the end of the 4th cataract above Merowe have been hidden beneath a deposit of sandstone again appear. This cataract of Hannek, which with that of Kaibar has been mapped and described by Gottberg[1] is according to him 6·47 kilometres long with a fall of the water surface of 5·525 metres at low stage and 3·20 metres in flood (1856)[2] which is made up of seven drops of various sizes the steepest being 0·86 metre in 60 metres.

This region was geologically examined in 1902 by Dr. W.F. Hume who found that in the southern portion of the cataract the fundamental rock is gneiss which is traversed by bands of granite, and these give rise to rapids whenever they occur in consequence of their superior power of resistance to the erosive action of the river ; further down the cataract the rocks are of the same character except that in the plain on the western side patches of white marble occur as intercalated bands, but it is still the granite dykes which form the successive groups of rapids.

Kaibar Cataract, 63 kilometres below Hannek, is much shorter being only 400 metres in length and causing a fall in the water surface of 3·5 metres at low stage and 0·30 metre at high flood (1856),[3] when it is practically invisible. It is caused by a low belt of gneiss which rises beneath the overlying sandstone and has been brought to light by the river having cut down through this upper rock.[4]

Beyond Kaibar the river is unobstructed for 110 kilometres when the Amara rapids are reached, but these form no serious obstacle, and are succeeded by 38 kilometres of clear water before the Dal cataract. The Amara rapids are caused by a mass of schistose rocks, while at Dal a coarse granite forms the river bed and the islands which separate the stream into several branches.[4]

The Akasha rapids occur at a point where the Nile flowing east and west for a short distance meets the gneiss which is striking north and south ; after the rapids the river turns northwards and flows parallel

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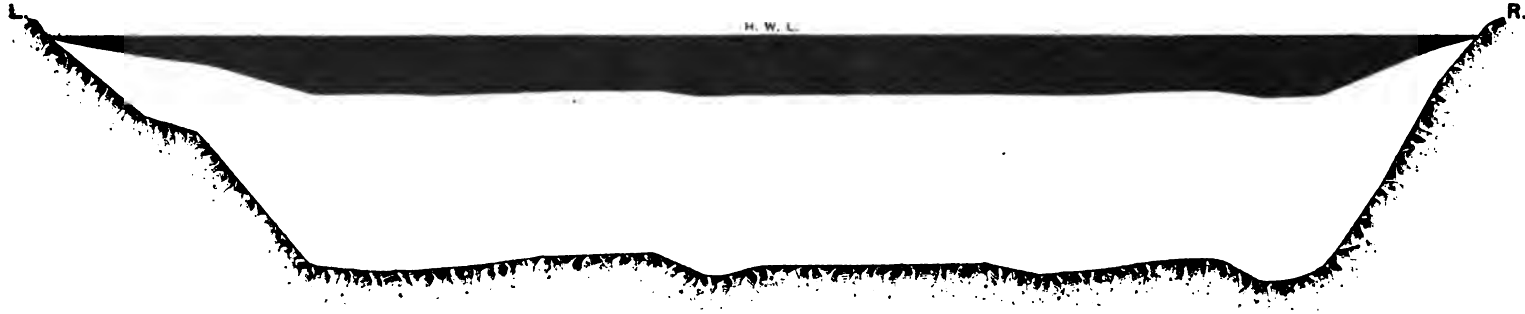
1 "Les Cataractes du Nil," Paris 1867.
2 This was a high flood rising to 0·83 metre above the mean maximum reading at Roda for the years 1825-1872 see Chap. VIII.
3 Gottberg loc. cit.
4 Dr. W. F. Hume.

SECTIONS OF THE NILE

Upper part of Shabluka Gorge 84 Km. from Khartoum 30·9·03.



Kerreri 20 Km. from Khartoum 24·5·03.

HORIZONTAL SCALE 1 : 2,000

metres 20 10 0 20 40 60 80 metres

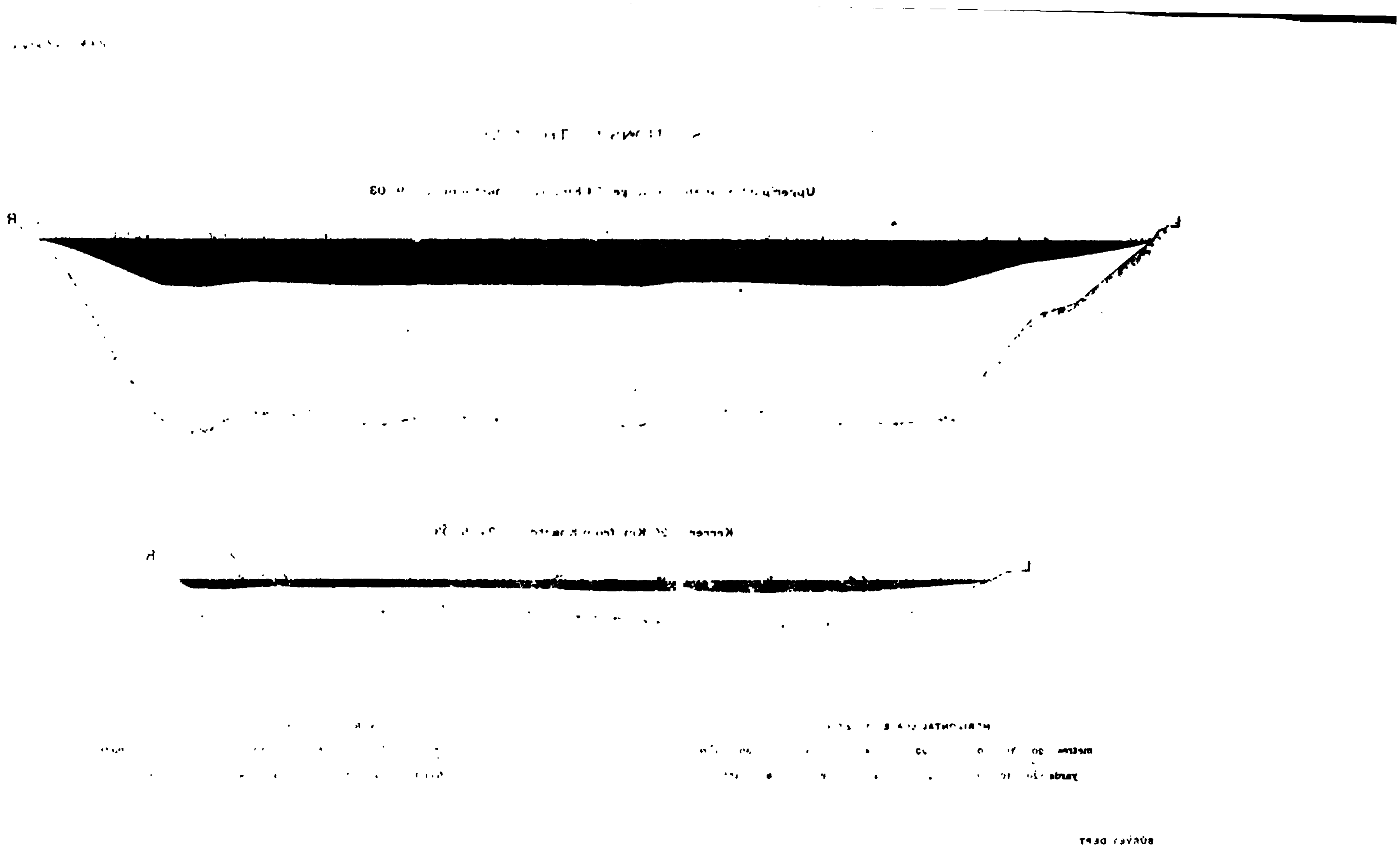
yards 20 10 0 20 40 60 80 yards

VERTICAL SCALE 1 : 500

metres 5 0 5 10 15 20 metres

feet 10 0 10 20 30 40 50 60 feet.

SURVEY DEPT.



to the direction of the beds of gneiss. It is probably this structure which has determined a characteristic feature of the river in this part, namely that it consists of northerly reaches interrupted by short lengths which run almost due east.[1]

Beyond this point an intermixture of granite and schists occur, the former giving rise to the small rapids of Tanjur, Ambigol, and Wadi Atiri, after which 12 kilometres south of Sarras is the gorge of Semna.

At this point a band of red and grey gneiss[2] forms a barrier across the river over which it flows in flood but at low stage it passes through a narrow central channel about 40 metres wide, (see Plate XXXIV*b*.).

The foliation planes of this rock strike parallel to the direction of the river and dip to the south-east, being very fissile; the annual scouring of the rock by silt and sand carried down by the river flood has polished the sloping sheets of rock while deep pot-holes have been worn in the barrier. There is certainly at this point an exceptionally large amount of erosion taking place as the flood waters slowly grind down the barrier of gneiss. This place is of special interest as there is also historical evidence that a very considerable amount of the barrier has been removed by the river within the last 4000 years. There seems to be little doubt that this has actually taken place but it is desirable that it should be confirmed by a study of the alluvial deposits up-stream of the barrier where there should be clear evidence of so marked a change in the water level.

In this section about 450 metres wide the Nile flows betwen two hills called Semna and Kumna on each of which is an ancient temple standing within the walls of a fortress of the XII Dynasty. Eighteen inscriptions on the west bank, first noticed by Lepsius, record the height of certain Nile floods in the reigns of Amenemhat III, Amemenhat IV and the first two kings of the XIII Dynasty, covering a period of about 50 years from 1800 to 1750 B.C.[3] and show that the level of these floods was about 7·30 metres above those of the present time. This would have submerged the Wadi Atiri rapids and given navigable water from Semna to Ambigol.

At Gemai a short distance above the Wadi Halfa or Second Cataract a bar of massive granite with diorite cuts across the river forming four islands, but the main cataract below is wholly different in its structure.

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1 Dr. W. F. Hume.
2 Ball. Quart. Jour. Geol. Soc.. vol. LIX. 1903, p. 65-79.
3 Cf. Borchardt, "Zeitsch. Aegypt. Sprache." Leipzig 1899, p. 101.

Here, instead of a few granite reefs each forming a series of rapids, we find numbers of islands, some 60 being fairly large, while the total number reaches about 200. Granite and gneiss are rare and the principal rocks are a series of dark hornblendic rocks, which are often much crushed, and are cut by numerons dykes of dolerite and other rocks, enabling the river to erode a network of channels most of which are shallow and dry at low stage.[1]

From Wadi Halfa to Aswan Cataract the river is navigable and free from rocky barriers. A marked feature is the series of well-built spurs of large boulders which have been placed at right angles to the bank to cause deposit of silt which can be cultivated at low Nile ; similar ones occur in the neighbourhood of Hannek. The boulders are darkened by long exposure and they probably date from ancient Egyptian times though there seems no evidence to connect their construction definitely with Ramses II as has been stated.[2] In this reach only sandstone is met with until the villages of Abu Hor and Kalabsha where granite with diorite veins again occurs.

The first or Aswan Cataract is again different in some degree to the Second and Third Cataracts; the islands which fill the river bed at this point are due rather to the lines of weakness caused by faulting than to dykes of a less resistant rock. There has been considerable movement and crushing in former times and the soft rock which was met with when the foundations of the western portion of the dam were being excavated, was such a crushed and schistose mass.[3] It has been stated that on other lines of section continous solid granite occurred[4] but the geological examination of the cataract affords no support to this contention and there is no doubt but that the water channels are everywhere determined by less resistant rock which has usually been crushed along lines of faulting.

The effect on the river of these ridges of crystalline rocks, which form rapids and cataracts at numerous points between Khartoum and Aswan, is to delay the formation of a regular slope or grade since they offer a much greater resistance to the erosive action of the stream than do the alluvium and sandstone which occur between them. Thus we have a series of reaches with a low slope separated by short lengths of rapids where the slope is greater and where the erosive action of the river,

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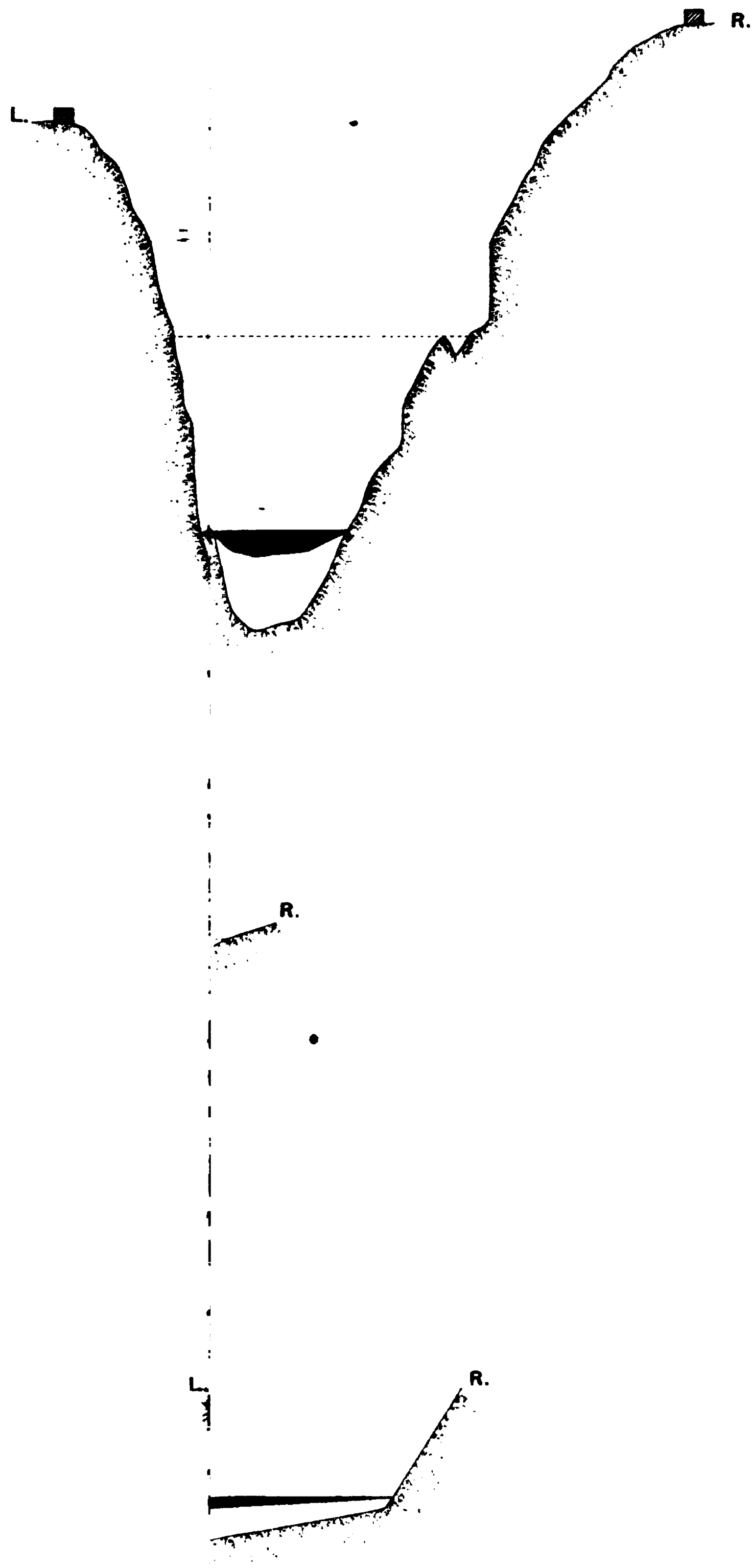
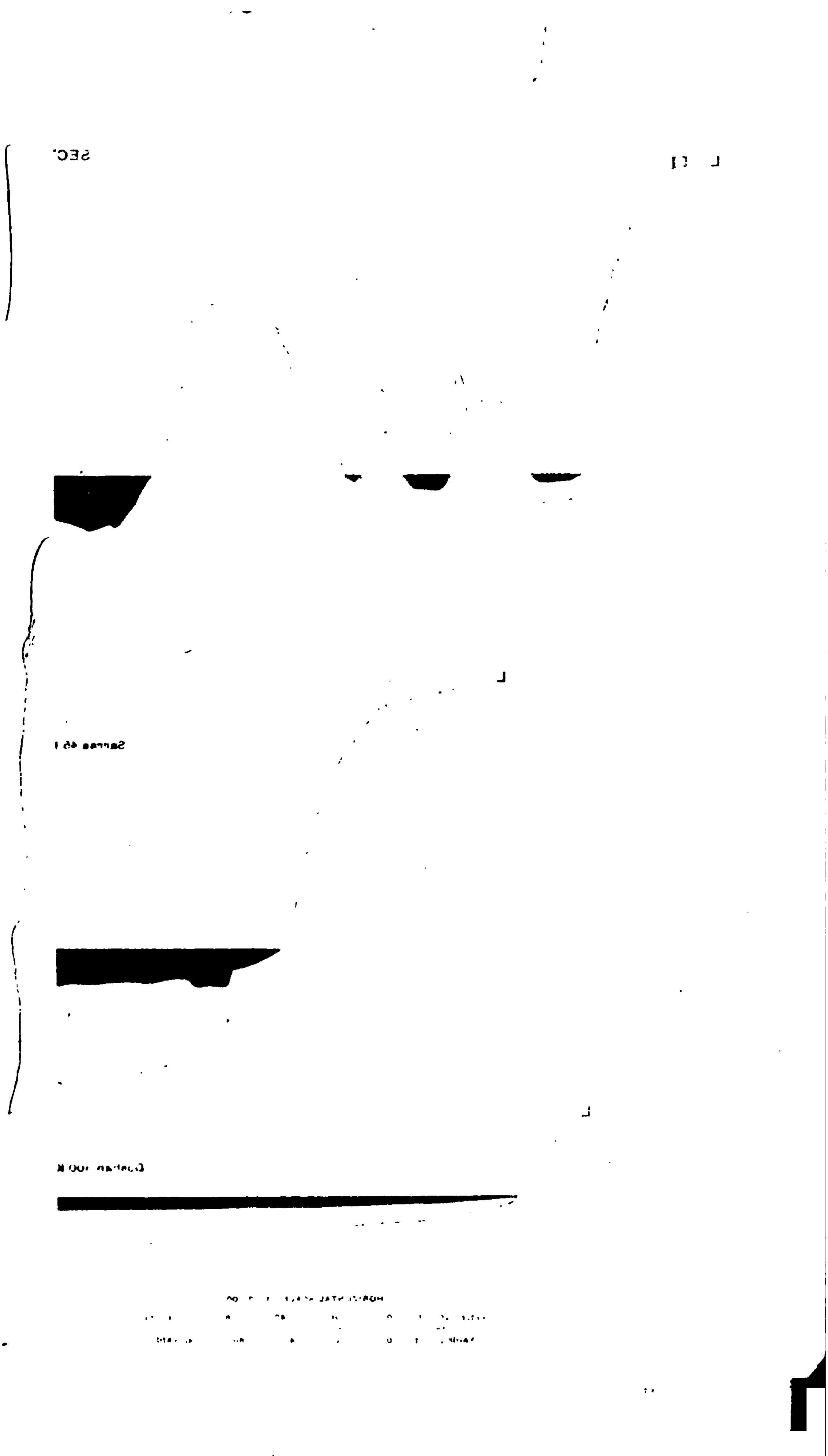
1 Dr. W. F. Hume.
2 Egyptian Irrigation, p. 31.
3 Dr. J. Ball. The Geology of the Aswan Cataract, Survey Dept. Cairo (in the press).
4 The Nile Reservoir Dam at Aswan, London 1901, p. 7.

PLATE XXXIV b.



SURVEY DEPT.



especially in flood, is wearing away the obstruction. No detailed examination of the Shabluka gorge or of the 4th and 5th cataracts has yet been undertaken to show if these have been appreciably eroded in recent times, but at Hannek Gottberg states[1] that river alluvium occurs 3·5 metres above the present floods thus showing that this amount of erosion has taken place comparatively recently. At Semna Ball[2] has maintained that the position of flood marks of the XII Dynasty (1875 B.C.) 8 metres above present flood level is due to the erosion of this amount from the barrier of gneiss which here crosses the valley ; the height of the cultivated flood plains, which are well above the present floods at places such as Derr, also bears witness to the slow grading of the river bed which has been much retarded by these hard rocky bars occurring in it. Without them the Nile from Khartoum to Aswan falling about 275 metres in 1875 kilometres would have a slope of 1 in 6,800 instead of a number of more level reaches ; for example, from Merowe to Hannek the river falls about 30 metres in 336 kilometres or 1 in 11,200; from Wadi Halfa to Philae Island it falls 29 metres in 345 kilometres or 1 in 11,900. The mean slope from Khartoum to the sea is 1 in 8,200 so that when the rock barriers are finally removed the grading of the river bed will entail a considerable steepening of the slope in Egypt where from Aswan to Cairo it is at present 1 in 13,000.

Under these circumstances it will be seen that the Nile below Khartoum is a river in a comparatively early stage of its development, and is still a long way from having graded its bed to a nearly uniform slope.

Hydrography.—The old Khartoum gauge was erected in 1864,[3] when Musa Pasha was governor of the Sudan, and daily readings were taken from the first commencement of the rise till the flood was past. It is not known whether these began in 1865, but only series of daily gauge readings at Khartoum which now exists is from 1869 to 1883 ; these were taken daily from about the middle of May till the end of October, or the early part of November.

	1869	1870	1871	1872	1873	1874	1875	1876
From	May 19	May 19	May 17	May 8	May 11	May 8	May 8	May 8
To	Nov. 9	Oct. 29	Sept. 28	Oct. 2	Sept. 24	Nov. 9	Nov. 9	Nov. 9

[1] Loc. cit., p. 48.
[2] Quart. Jour. Geog. Soc., vol. lix. 1903, p. 66-79.
[3] Pet. Mitt. 1864, p. 308.

	1877	1878	1879	1880	1881	1882	1883	
From	May 10	May 10	May 10	May 10	May 8	May 19	May 19	
To	Oct. 15	Oct. 20	Oct. 29	Oct. 29	Oct. 29	Oct. 29	Oct. 29	

These were interrupted by the Mahdist revolt, and were not resumed until 1900, from which date they have been recorded daily throughout the year up to the present time. It has not been possible to determine the site of the old gauge of 1869-83 with sufficient accuracy to refer the readings of the present gauge to it. The gauge in use today is opposite the office of the Department of Works on the left bank of the Blue Nile about 4 kilometres upstream of its junction with the White Nile (see Plate XXXIII) and about 3 kilometres below the point where the discharges were taken. Its zero was found to be 369·1 metres (1213 feet) above Suakin sea-level according to the recent railway survey, or 376 metres (1233 feet) above the Mediterranean sea-level according to the railway survey from Wadi Halfa to Abu Hamed. Previous levelling had given 378 metres for the altitude of Khartoum,[1] apparently for the general ground level, probably based on a line of levels carried by Ismail Pasha el Felaki, the astronomer, from Suakin to Shendi, by which he determined flood level of 1866 at Shendi to be 363·23 metres and the low stage of 1867 to be 354·76 metres above sea-level. The railway line here according to the railway levels is 371·5 metres (1218 feet). From these somewhat discrepant data it seems very probable that the true level of the zero of the gauge is not far from 370 metres which is the value which the Irrigation Department has assumed for the present.

Rise at Khartoum.—At Khartoum the rise commences quickly; for a few days the gauge shows a slight increase, and then rises steadily. In most years there are small rises and falls which interrupt the steady rise, due to variations in the volume of water poured in by the different tributary streams in the upper reaches of the river. In the mean curve taken from fourteen years (1869-83), Plate XXXV these irregularities do not appear, and a steady rise is shown, which varies from one metre in fifteen days at first to one metre in ten days at the end of July. In the middle of August the rise becomes slow, and the flood stage is reached usually at the end of the first week in September. The fall then commences, and by September 20 is well advanced, the gauge falling a metre in about sixteen days.

[1] Tissot "Statistique de l'Egypte," Cairo, 1873.

Similar mean gauge curves are given on Plate XXXV for Wadi Halfa and Aswan. Though these are not for the same fourteen years as the Khartoum curve, all the three probably differ but very little from the true mean curves, and may be compared with one another without introducing any error. They are similar in general character, but differ somewhat in the shape of the curve. While the Khartoum curve rises at once and with a fairly regular increase, those of Wadi Halfa and Aswan rise very slowly for the first three weeks, and then a more rapid rise takes place.

This is clearly shown in the following table, taken from the mean curves :—

Days after May 20	Rise of mean gauge at—					
	Khartoum	Rise in ten days	Wadi Halfa	Rise in ten days	Aswan	Rise in ten days.
	metres	metre	metres	metre	metres	metre
10	0·47	0·47	0·00	0·00	0·00	0·00
20	1·01	0·54	0·10	0·10	0·08	0·08
30	1·51	0·50	0·30	0·20	0·30	0·22
40	2.25	0·74	0·75	0·55	0·86	0·56
50	3·10	0.85	1·25	0·50	1·55	0·69

The delay of the rise at Wadi Halfa is due to the amount of water which is taken up by the sandbanks and the low shallow reaches between the cataracts when the flood first comes down. About a month's delay is caused by this together with the move of the flood-wave from Khartoum to Aswan, before the flood can be said to be rising rapidly at Wadi Halfa, where the first rise is felt apparently about fifteen days after the rise has commenced at Khartoum. The fall begins at Khartoum about September 20, and at Wadi Halfa and Aswan a few days later.

The fifteen years of gauge-readings at Khartoum from 1869 to 1883 do not cover exactly the same period of each year. Though in ten years the readings begin on the 8th, 9th, or 10th of May, in the first five years it is not until the 18th or 20th, while they end on various dates from

September 5 to November 8. It is not, therefore, quite certain that the absolute lowest reading of the year is recorded ; but in all cases the lowest reading given must be very near it, while in every year except 1869 the maximum can be found without any doubt.

The following table gives the lowest and highest readings recorded, together with the range for each year :—

Year	Lowest gauge-reading	Highest gauge-reading	Range
	metres	metres	metres
1869	5·44	13·50	8·06
1870	5·40	13·32	7·92
1871	6·48	13·00	6·52
1872	6·52	13·31	6·69
1873	6·48	12·42	5·94
1874	6·57	13·77	7.20
1875	6·48	13·25	6·77
1876	6·48	13·50	7·02
1877	6·52	11·74	5·20
1878	6·55	14·06	7·51
1879	7·93	13·32	5·39
1880	5·82	12·80	6·90
1881	5·92	13·23	7·31
1882	5·44	12·64	7.20
1883	5·92	13·34	7·42
Means	6·26	13·14	6·88
1900 [1]	−0·48	+6·27	6·75
1901	−0·08	+6·10	6·18
1902	−0·10	+5·50	5.60
1903	−0·26	+6·20	6·46
1904	−0·01	+5·64	5·65
1905	−0·25	+5·54	5·79

−0.197 5.58 6.07

Dr. Peney [2] gives the mean range of the Nile here as 6 metres as the mean of ten years' observations between 1840 and 1860, but this would seem to be too low a value.

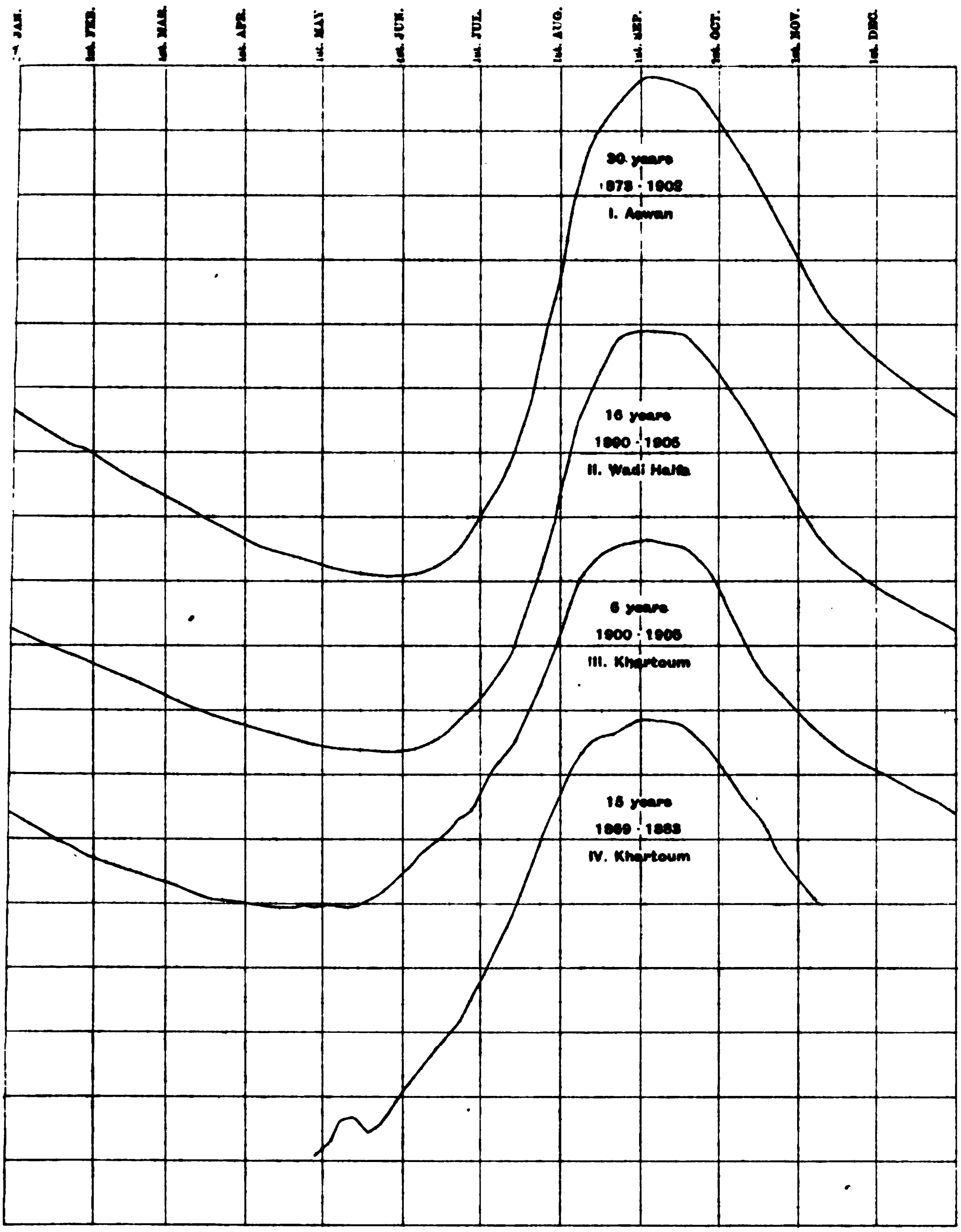
The Nile is at its lowest at Khartoum in the middle of May, just before the White Nile begins to rise, and when the Blue Nile flood has not yet arrived. For the twenty-one years 1869-1883 and 1900-1905, the average date of the lowest gauge-reading at Khartoum was May 11 ; the extreme dates being April 16, 1900, and May 29,1882.

[1] A different gauge.

[2] Bull. Soc. Geog., Paris. July. 1863, p. 33.

PLATE XXXV.

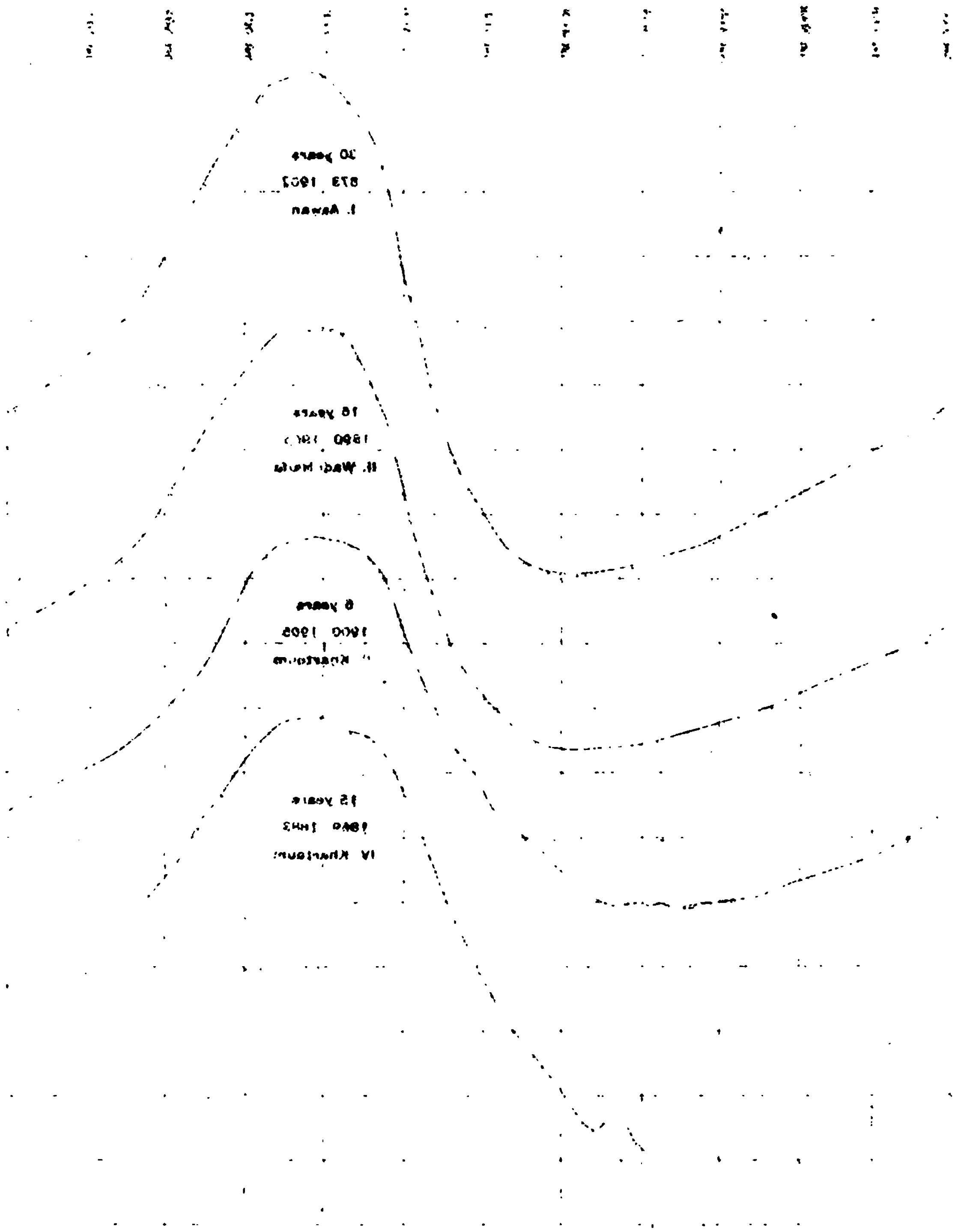
MEAN CURVES OF NILE.



SCALE 1 : 100

NOTE : The space between horizontal lines represents 1 metre rise of water surface.

MEAN CURVES OF NILE.



NOTE. — The space between horizontal lines represents 1 metre rise of water gauge.

The highest level at Khartoum is usually reached early in September, the earliest date in these years being August 16, and the latest September 29, 1881, when the Abyssinian rains were unusually prolonged, though they were not heavy. The mean date for the maximum deduced from these years is September 6, and the mean deviation from this date is ten days.

Year	Date of lowest reading	Difference from mean date	Date of highest reading	Difference from mean date
1869	May 19	+ 8	Sept. 5	− 1
1870	„ 20	+ 9	Aug. 17	−20
1871	„ 17	+ 6	„ 16	−21
1872	„ 8	− 3	Sept. 6	0
1873	„ 12	+ 1	„ 2,9,10	0
1874	„ 8	− 3	„ 4,5	− 2
1875	„ 8, 16, 25	+14	„ 20	+14
1876	„ 8, 21	+10	„ 12	+ 6
1877	„ 10	− 1	Aug. 29, 30	− 7
1878	„ 10	− 1	Sept. 21, 22	+16
1879	„ 10	− 1	„ 9, 10,11	+ 4
1880	„ 13	+ 2	„ 23	+17
1881	„ 20	+ 9	„ 29	+23
1882	„ 29	+18	Aug. 28	− 9
1883	„ 24	+13	Sept. 11	+ 5
1900	April 16	−25	Aug. 17	−20
1901	„ 18	−23	„ 1, 20	−11
1902	May 6	− 5	„ 14	+ 8
1903	„ 15	+ 4	„ 4	− 2
1904	„ 10	− 1	„ 11	−26
1905	„ 5	− 6	Sept. 6	0

Mean date of lowest reading, May 11.

Mean date of highest reading, September 6.[1]

Mean variation from date of maximum, ten days.

When the readings of the Dueim gauge and the Khartoum gauge are compared they furnish an instructive picture of the interaction of the Blue and White Niles at their junction as shown in the following description.

[1] This date is taken from the mean curve, Plate XXXV.

The interaction of the Blue and White Niles.[1]—In an extremely interesting and instructive paper Tommasini[2] has discussed the discharge curve at Khartoum with reference to the discharge formula based on Kutter's expression[3] for the mean velocity in terms of the slope and hydraulic mean depth. The decrease of the discharge corresponding to a given gauge-reading on the ebb of the flood as compared with that corresponding to the same reading on the flow he attributes to the decrease of the slope on the ebb. In symbols, if F and E represent the discharges on the flow and ebb respectively, which correspond to the same gauge-reading, and therefore to the same hydraulic radius r, and if s and s' represent the slopes, then

$$F = C \sqrt{r^3 s}$$
$$E = C' \sqrt{r^3 s'}$$

And since C and C′ may be taken as approximately equal

$$F : E = \sqrt{s} : \sqrt{s'}$$

In the following table two pairs of discharges of the Blue Nile taken on the flow and ebb are compared :

No.	Date	Discharge Cub. metr. per sec.	Gauges Khartoum metres	Gauges Wad Medani metres	Mean Slope	$\sqrt{S}$
10	Aug. 1, 1902	3420	3·34	7·56	1 : 10400	1 : 102
12	„ 15, „	4720	4·50	8·96	1 : 10200	1 : 101
19	Oct. 3, „	4880	5·03	9·70	..	..
20	„ 10, „	3250	4·45	8·00	..	..
22	„ 24, „	2050	3·40	6·78	..	..
23	„ 31, „	1244	3·00	6·04	..	..
20a	(„ 9, „)	3390	4·50	8·02	1 : 10600	1 : 103
22a	(„ 25, „)	1912	3·34	6·68	1 : 10900	1 : 104.5

[1] By Mr. J. I. Craig, Chief Inspector Survey Department.

[2] Delle Scale di Deflusso, " Ann. Soc. Ingegneri e Architetti Italiana," Rome, 1905.

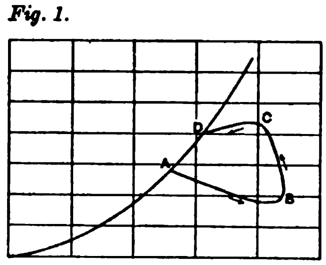
[3] $r = C\sqrt{(rs)}$ where $C = (23 + \cdot 00155/s + 1/n) / [1 + (23 + \cdot 00155/s) n / \sqrt{r}]$, n being a constant depending on the roughness of the bed, the value of which for the Nile may be taken as ·025.

The first column gives the numbers assigned to the discharges by Tommasini and the fourth the gauge-readings to which they are referred. Since his 20 and 22 are on different gauge readings from 12 and 10, the former have been adjusted with the help of 19 and 23 to get 20a and 22a. The altitude of the zero of Khartoum gauge being taken as 370 metres, that of Wad Medani is 384·76 m.[1] Hence with the gauge readings at Wad Medani, given in column 5, the slopes in column 6 may be computed. In accordance with the proportion above, the discharges ought to vary as the square roots of the slopes; that is, 20a ought to be less than 12 by about 2 % and 22a about 2·5 % less than 10. If we take account of the changes in C in Kutter's formula, these percentages will become about 2·6 and 3·1 respectively or say 3 % for both. But a glance at the third column will show that the differences are much greater than that, being in fact 28 % and 44 % in the two cases.

It follows therefore that the difference between the discharges at Khartoum on the rising and the falling stages of the river are not due entirely to the general change of slope from the flow to the ebb, which cannot differ much from the mean slope between Wad Medani and Khartoum, and some local explanation must accordingly be sought for the phenomenon. We have such in the action of the White Nile and the Dueim-Omdurman basin.

Tommasini has shown the effect on the discharge curve due to a spate on a tributary coming in just down-stream of the gauge on the main river, when the latter is rising. If A D (fig. 1) represent the normal discharge curve of the river under consideration (which may or may not be more important than the tributary) the effect of a sudden

Fig. 1.



flood on the tributary is to deform the parabolic shape of the regular discharge curve by attaching the loop A B C D.[2] At A, the tributary

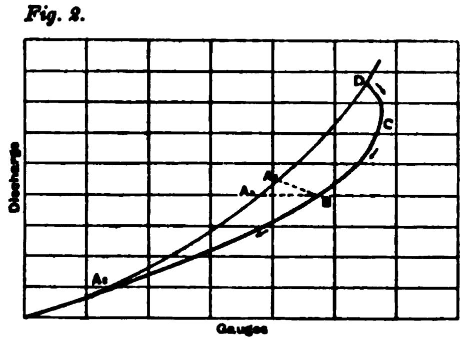
[1] By recent levelling,
[2] Tommasini loc. cit. par. 11.

begins to hold up the main river, so that up to B, there may even be diminished discharge with increased gauge-reading. At B the tributary has already begun to ebb and the discharge goes on increasing, even though the gauge falls, up to C, when a temporary maximum is reached. To D the discharge and gauge fall together, and at that point the effect of the tributary ceases and the normal discharge curve is resumed. Local circumstances may modify the shape of the loop in an infinite variety of ways, but its essential features remain the same.

Tommasini has shown how this gives an adequate explanation of the behaviour of the White Nile at Dueim under the influence of the flood on the Blue Nile. It is proposed to show that a similar explanation attaches to the phenomenon of the ebb on the Blue Nile as affected by the flow on the White Nile.

The case is exactly the converse of that just illustrated. Were the White Nile absent, the discharge curve for the Blue Nile would have a form analogous to that shown by the full line in the diagram (Plate XXV), where the discharges on the ebb are about 3% less than those on the flow.[1] If we consider, however, the effect of a tributary coming down in flood when the main river is falling we shall get a curve similar to that in *fig. 1* but traversed in the reverse direction, except that the upward direction of the part from D to C will be impossible, since holding up will not cause the main river to discharge more. The shape of the loop would therefore become somewhat similar to that in fig. 2.

Fig. 2.



From D to C, the tributary is rising and causing the main river to rise with it up to a maximum gauge-reading at C. From C to B, gauge and discharge fall together, though not equally, and from B the

[1] In the diagram the difference is rather more than 3%.

curve may take any of the directions BA_1 BA_2 BA_3 according as the effect of the tributary dies away more or less rapidly. On the other hand if the tributary does not rise more rapidly than the main stream is falling, the effect at D will be that none of the loop lies to the right of that point. A large reservoir on the tributary, just upstream of the junction, would cause the arc D to C to run perpendicular to the gauge-axis until the reservoir began to fall, and this part of the curve would be useless for gauging purposes, except as giving limits to the discharge.

Now this is exactly the case of the White and Blue Niles after the latter has begun to fall. For, as will be shown later, between Dueim and Omdurman we have a reservoir storing some 1500 million cubic metres of water at the time the Blue Nile is at its highest. And further, owing to the lateness of the flood on the Sobat, the White Nile does not reach its maximum discharge till some two or three months after the Blue Nile has begun to fall. From these two causes combined, the normal branch of the discharge curve at Khartoum on the ebb will be modified by the attachment of a loop on the right, as has just been explained, and the discharge curve will take the shape shown by the dotted line in fig. 2.

We may now consider the effect of the Blue Nile on the White Nile. The levels run by the Sudan Irrigation Department give the altitude of the zero of Dueim gauge as 372·0 metres, if that of Khartoum gauge be taken at 370·0. The mean slope of the Blue Nile is about 10 centimetres per kilometre or 1 in 10,000 and the gauge is some 5 kilometres up-stream of the junction with the White Nile at Omdurman. Hence the fall of the water surface to the junction will be 0·5 metre. If then we plot the Dueim and Khartoum gauges against the time, but add 2·5 metres to all the former, we shall have two curves giving at each date the difference of level between the water surfaces at Dueim and Omdurman. This has been done on Plate XX. It should, however, be mentioned that up to April 1903 the Dueim gauge consisted of a movable vertical scale, the position of which was changed from time to time as the water rose or fell. No regular references to a benchmark were made, and the recorded absolute heights of the water surface in the first two years have not the same accuracy as they now have.

Apparently in 1902 the zero of Dueim gauge was 1·4 metres above that of Khartoum, while in 1903 it was 1·5 metres. We know from other data that in the former year the Blue Nile began to affect the White Nile at Dueim, in the manner about to be described, about

August 8, while in 1903 the date at which the effect reached Dueim was about the end of July. We should therefore expect the curves to become coincident or nearly so about these dates, and they have accordingly been so plotted.

The action of the gauge at Dueim may best be described by taking 1905, the first year in which accurate data as to gauge levels are available. During the low stage the White Nile is the dominant factor. This is shown in several years by the reproduction of several temporary waves at Khartoum from two to three days after they have passed Dueim. As soon as the Blue Nile begins to rise, the lower part of the basin which lies between Dueim and Omdurman begins to rise with it, and a part of the White Nile discharge is used up in this process. Gradually as the Blue Nile rises, more and more of the basin is filled and a greater proportion of the Dueim discharge is utilized. When the Blue Nile has risen 2·5 metres at Omdurman (2 metres at Khartoum) more than the White at Dueim the basin is flooded with what is practically a level sheet of water. The flooded area extends till the Blue Nile reaches its maximum gauge, at which point some 500 cubic metres per second of Dueim discharge are being utilized in filling the White Nile valley and for replacing the loss by evaporation over the surface of the basin ; the net discharge above Omdurman sinks to about 300 cubic metres per second. As the Blue Nile falls, the basin begins to empty and the slope reasserts itself. In the meantime, however, the White Nile upstream of Dueim has been slowly but steadily rising, and on the first gradual fall of the Blue Nile after the maximum, this rise is felt at Dueim, as will be observed in almost every one of the curves on Plate XX. The Khartoum gauge, however, soon begins to drop rapidly and the corresponding fall in the basin level reaching to Dueim masks the rise due to the upper White Nile flood, which is only evidenced in the more gradual fall of the Dueim gauge. The rate of emptying the basin appears to reach a maximum about the middle of October, when an amount of about 220 metres per second more is passing Omdurman than Dueim, in spite of the enormous loss from evaporation. Although the discharge at the latter place continues to increase until about November 20, owing to the fact just mentioned the chief contribution of the White Nile to the combined river occurs about five weeks earlier.

To get a more accurate estimate of the part played by the Dueim-Omdurman basin, calculations of the amount of water stored in the

river channel between the lowest stage surface-plane and the surface at ten-day intervals have been made. They are based on a water surface of 185 square kilometres between these places at low stage, which was found by measurement from the Intelligence Department maps, scale 1 : 250,000. It is much more difficult to get an accurate value for the flooded surface. On the right bank this area is small, but in places on the left bank the water reaches to distances of 6 to 7 kilometres measuring from the right bank. At Dueim the ratio between the two surfaces is almost 2 to 1, which has therefore been adopted as a minimum value. The flooded surface therefore becomes 370 square kilometres.[1] Taking 1903, the year for which the most complete series of discharges exists, we find that the lowest stage was reached about May 11 when the Dueim gauge registered 0·33 metre and the Khartoum gauge 0·25 metre, while the highest stage was reached about September 8, with readings of 4·43 metres and 6·15 metre respectively. The flooded area will increase slowly at first and more rapidly later, in some what of a parabolic ratio. Two separate calculations show that the exact form of the curve giving the increase of the water surface has only a secondary effect on the actual amount, within the limits 185 and 370 mentioned above. The area of the water surface between Dueim and Omdurman corresponding to different gauges having been calculated, it becomes possible to compute the contents of the trough above the low-stage surface. This was done for each tenth day from May 1st to the end of the year and the results tabulated as in the following table.

[1] It appears that the maximum flooded area between Omdurman and Dueim may be about 500 square kilometres. The greatest quantity of water for any ten days interval will naturally be required when the Khartoum gauge is rising very rapidly. The subjoined figures give the modification thus introduced in columns 7, 8 and 9 of the table on page 271 from which it will be seen that there is no necessity to modify the conclusion reached on page 272, that the flow of water past Dueim is in general adequate to fill the basin.

	Loss before Omdurman	Discharges			Loss before Omdurman	Discharges	
		Dueim	Omdurman			Dueim	Omdurman
	m³ per sec.	m³ per sec.	m³ per sec.		m³ per sec.	m³ per sec.	m³ per sec.
May 1	10	430	420	July 20.. ..	280	800	580
„ 11	60	440	380	„ 30.. ..	660	770	110
„ 21	60	490	430	Aug. 9.. ..	550	560	10
„ 31	260	580	320	„ 19.. .	400	660	260
June 10	140	650	510	„ 29.. ..	190	580	390
„ 20	20	810	790	Sept. 8.. ..	140	670	810
„ 30	190	860	670	„ 18.. ..	90	770	680
July 10	160	830	670		etc.	etc.	etc.

Table of contents and discharges of the Dueim Basin

Date	Area Square Kilometres	Volume Millions cub. metres	Change of volume per day	Evaporation Millions cub. metres	Loss before Omdurman: Millions m³ per day	Loss before Omdurman: m³ per second	Discharges: Dueim m³ per sec.	Discharges: Omdurman m³ per sec.	Discharges: Blue Nile m³ per sec.	Discharges: Total m³ per sec.
1903										
May 1	186	16·7	— 1·7	2·8	+ 1·1	+ 13	430	420	60	480
" 11	185	0·0	+ 2·2	2·7	+ 4·9	+ 57	440	380	0	380
" 21	186	22·2	+12·9	2·8	+15·7	+183	490	310	190	500
" 31	194	151·5	+ 5·9	2·9	+ 8·8	+103	585	480	990	1380
June 10	198	210·8	+ 8·0	3·0	+11·0	+128	650	520	1030	1550
" 20	203	290·8	— 1·7	3·0	+ 1·3	+ 15	810	800	1150	1950
" 30	201	273·8	+11·7	3·0	+14·7	+171	860	690	1500	2190
July 10	208	391·1	+ 8·6	3·2	+11·8	+138	830	690	2170	2860
" 20	219	476·8	+12·8	3·4	+16·2	+189	800	610	3100	3710
" 30	242	604·3	+39·1	4·1	+43·2	+504	768	260	6640	6900
Aug 9	304	[illegible]	+25·9	4·8	+30·7	+358	560	200	9340	9540
" 19	342	1254·3	+15·7	5·2	+20·9	+244	660	420	9530	9950
" 29	362	1411·3	+ 5·1	5·4	+10·5	+122	580	460	8260	8720
Sept. 8	370	1462·5	—10·2	5·5	— 4·7	— 55	670	720	8760	9480
" 18	357	1360·3	0·0	5·4	+ 5·4	+ 63	770	710	8620	9330
" 28	356	1360·8	—20·9	5·1	—15·8	—184	1350	1530	6460	7990
Oct. 8	328	1151·8	—20·7	4·7	—16·0	—177	1580	1760	4780	6540
" 18	297	941·6	— 6·0	4·4	— 1·6	— 19	1570	1590	4200	5790
" 28	288	884·4	—16·5	4·1	—12·4	—145	1563	1710	2630	4340
Nov. 7	262	719·8	—14·6	3·7	—10·9	—127	1600	1720	2030	3750
" 17	237	574·1	— 7·3	3·5	— 3·8	— 44	1650	1690	1400	3090
" 27	224	501·1	— 8·1	3·2	— 4·9	— 55	1550	1700	1200	2900
Dec. 7	210	420·6	— 4 8	3·1	— 1·7	— 20	1430	1450	920	2370
" 17	207	372·2	— 2·2	3·1	+ 0·9	+ 10	1403	1390	750	2140
" 27	206	350·1								

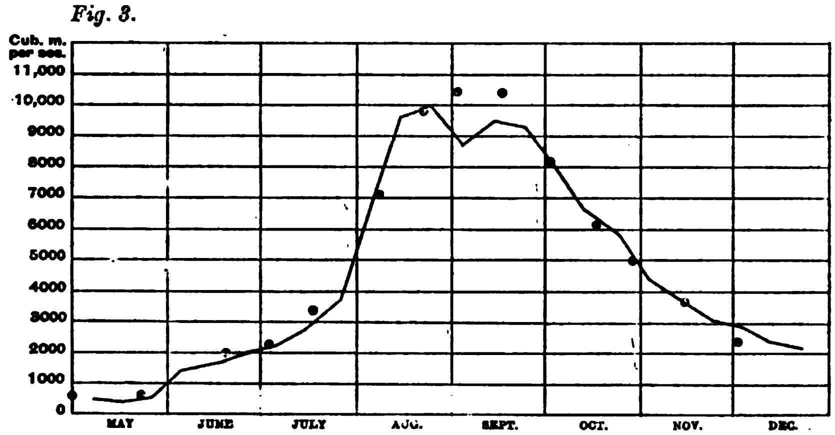
Differencing gave the increase of volume per ten days, whence the mean increase per day in the interval followed (Col. 4). The effect of evaporation is always to deduct from the Dueim discharge. The daily amount, based on an assumption of 10 mm. daily, which is about the value at Khartoum deduced from five months observations with a Piche evaporimeter extending over the flood period in 1905, is given in column 5. The next column gives the mean daily amounts thus lost (or gained where the sign attached is —) at Omdurman and column 7 the corresponding amounts in cubic metres per second. Column 8 gives the Dueim discharges got from the observed figures by interpolation and column 9 gives the derived discharge at Omdurman. The next two columns give the Blue Nile discharges interpolated from the observed values and the totals of these and the net White Nile discharges.

A comparison of columns 7, 8 and 11 shows that while the effect of the basin on the White Nile discharge was very considerable, that on the combined Nile was negligible. Further, it will be seen that the discharge at Dueim was more than adequate to fill the basin in every instance when ten-day intervals are taken. It might be that for quite short periods when the Blue Nile was rising rapidly, a stream flowed

from it up the White Nile, but the intruded water must quickly have been swept back to the combined river by the steady flow past Dueim.

The subjoined figure (fig. 3) shows graphically the computed combined discharge of Omdurman against the discharges actually measured at Kerreri or Shabluka. The agreement is satisfactory except in the period from August 24 to September 23 when the Blue Nile discharges fell rapidly for twenty days and then rose to maximum again. It appears that in this instance the discharges on the Nile are nearer the truth than those on the Blue Nile. There is nothing in either the Khartoum or Wad Medani gauges to account for a fall of such magnitude in the volume passing the former station.

Fig. 3.



Earlier measurements.—Until recently the available determinations of the volume of the upper Nile in flood have not been numerous, and the measurements which had been made did not agree well among themselves; besides this, the proportion furnished in flood by the White and Blue Nile respectively was quite uncertain. Linant considered them at the end of July to be practically equal; Peel made the Blue Nile to be double the volume of the White Nile at the end of October; but all observers agreed in describing the Blue Nile flood as sweeping across the White Nile, and forcing its stream of whitish water against the left bank, while the Blue Nile flood of muddy reddish water occupied the greater part of the channel.

The discharges measured by older travellers, together with those recently obtained, comprise the data that exist at present for comparing the volumes of the two main streams and their different tributaries.

Discharge of the Nile at Khartoum.—The first who measured the discharge of the Nile at Khartoum was Linant de Bellefonds[1] who measured the White Nile on March 4 and the Blue Nile on March 5, 1822, giving as the combined discharge about 456 cubic metres per second.

	White Nile, March 4	Blue Nile, March 5
Area of section..	582·8 square metres	360·3 square metres
Mean surface velocity .	0·51 metre per second	0·44 metre per second
Discharge..	297·2 cubic metres per second	158·5 cubic metres per second

In July, 1827, not in September as stated by Sir W. Willcocks[2] he again measured the discharge, with the following results[3]:—

	White Nile, July 26	Blue Nile, July 30
Area of section.	3924·5 square metres	3288·1 square metres
Mean surface velocity ..	1·54 metres per second	1·9 metres per second
Discharge	6043·7 cubic metres per second	6247·3 cubic metres per second

The combined Nile near Alifun[4] at the end of July, 1827, gave—

Area of section	... ...	6982·2 square metres
Surface velocity	... ...	1·72 metres per second
Discharge	... ...	12,000 cubic metres per second

but of course none of these July discharges represented the full flood.

The discharge of the combined stream below the junction does not appear to have been separately measured in March.

Petherick[5] gives the result of measurements of the White and Blue Niles at Khartoum on July 5, 1848 when he states the Nile was nearly

[1] Bull, Soc. Geog., p. 436, Paris, 1852.
[2] The Nile in 1904, p. 42.
[3] This must have been below the junction but today the only place of this name is some kilometres up the Blue Nile.
[4] Bull. Soc. Geog., p. 436, Paris, 1852.
[5] Egypt and the Sudan, p. 330, Edinburgh, 1861.

at its highest; but this cannot be the case, since the maximum reading of the Khartoum gauge occurs in September

Width	Greatest depth	Velocity
White Nile, 500 yards	22 feet	2¼ miles per hour
Blue Nile, 750 yards	20 feet	Nearly 2 miles per hour

These measurements correspond to sectional areas of about 2700 square metres and 4000 square metres respectively, and if the velocities were accepted, the discharges would be 3000 cubic metres per second for the White Nile, and 3700 cubic metres for the Blue Nile.

In October, 1851, a set of discharges was taken by Captain W. Peel[1]—

	White Nile	Blue Nile	Combined Nile
Width	480 yards	768 yards[2]	1107 yards[2]
Average depth ..	13·92 feet	16·11 feet	14·38 feet
Average velocity ..	1·17 knot per hour	1·564 knot per hour	2·0 knots per hour
Number of observations for velocity	10	7	7
Discharge	2,985,400 cubic feet per minute	5,820,600 cubic feet per minute	9,528,700 cubic feet per minute
Date	October 25.	October. 24	October 23.

The above results of Captain Peel, expressed in the metric system, are—

	White Nile	Blue Nile	Combined Nile
Average depth, metres	4·24	4·93	4·38
Average velocity, metres per second	0·757	0·806	1·03
Discharge, cubic metres per second	1410	2749	4500

In March, 1876, L. A. Lucas measured the velocity of the Blue Nile at Khartoum, but as he gives no measured section, the discharge cannot be satisfactorily deduced from his observations. In a letter to Dr. Schweinfurth, who has kindly communicated it, Lucas gives the average

[1] A Ride across the Nubian Desert. by Captain W. Peel. London: 1852.
[2] Taken as 760 yeards and 1090 yards for calculation by Captain Peel.

depth as 8 feet, and the greatest as 12 feet, the mean velocity as 5·69 feet per second, and the width as 560 yards.

This would mean a discharge of about 2000 cubic metres per second; but this is too high a value for March, and may be rejected.

In 1876, other measurements at Khartoum gave the following results in cubic metres per second[1]:—

	White Nile	Blue Nile
March	369	198, low stage
June	1050[2]	—
September	4351[2]	4398,[3] flood
December	2720	—

In April, 1883, both of the branches of the Nile at Khartoum were measured by J. M. Schuver.[4]

White Nile.—Taken on April 21,1883,200 metres above the junction with the Blue Nile, where the river was narrowed by an island. Above this point the river was 600-800 metres wide.

	Metres	Metres	Metres	Metres	Metres	Metres	Metres
Distance from east bank	30·0	55·0	80·0	94·0	108·0	138·0	158·0
Depth	0·5	2·5	4·0	5·5	8·5	4·0	1·0

Area of section = 524 square metres, while the velocity was 100 metres in 1 minute 10 seconds = 1·43 metre per second. Discharge = 750 cubic metres per second.

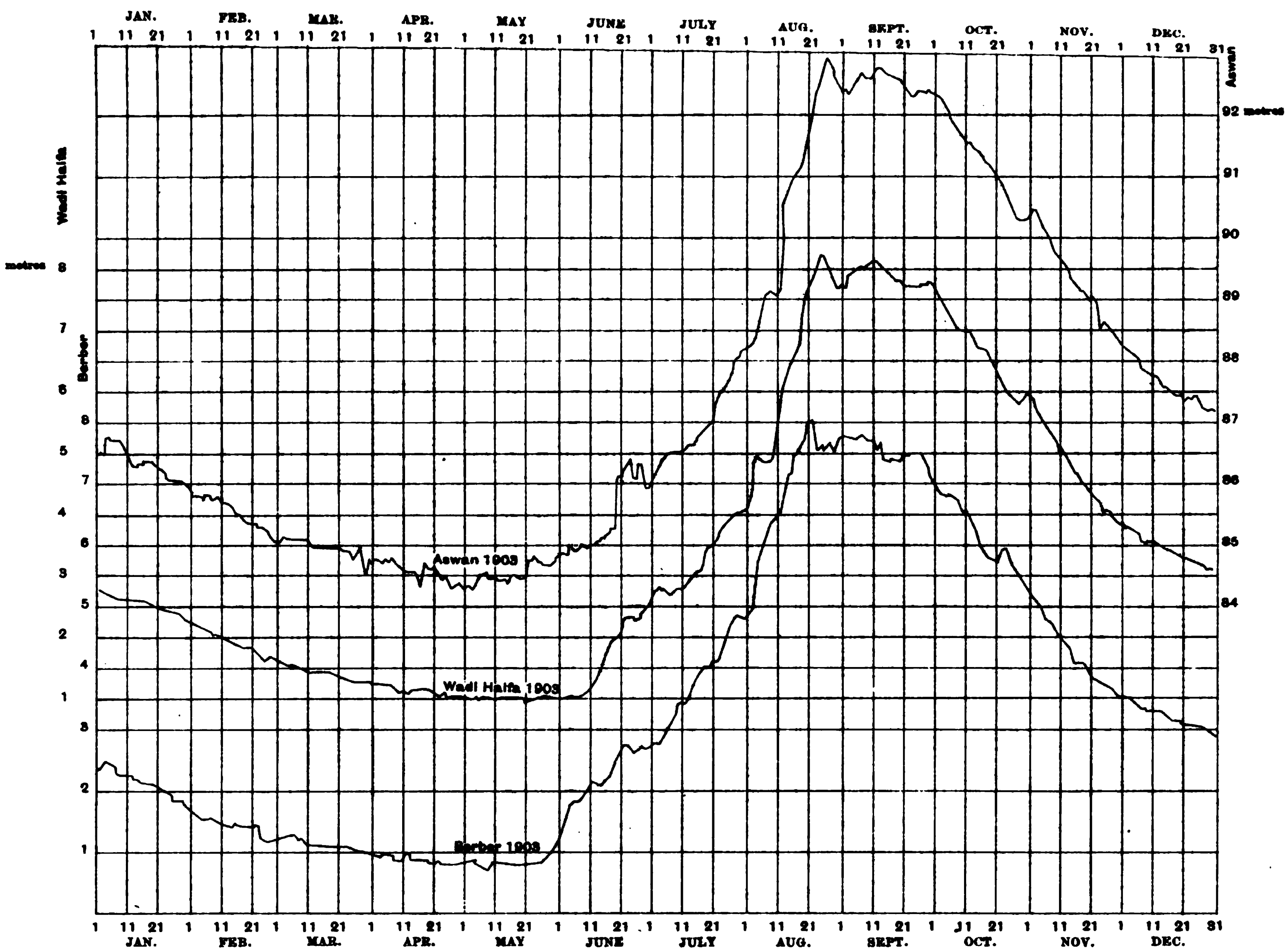
Blue Nile.—Taken on April 21, 1883. Of the total breadth of 320 metres, 140 metres was water and 180 metres sandbank.

	Metres	Metres	Metres	Metres	Metres
Distance from north bank ..	20·0	50·0	70·0	90·0	120·0
Depth	4·0	11·0	6·0	3·5	1·0

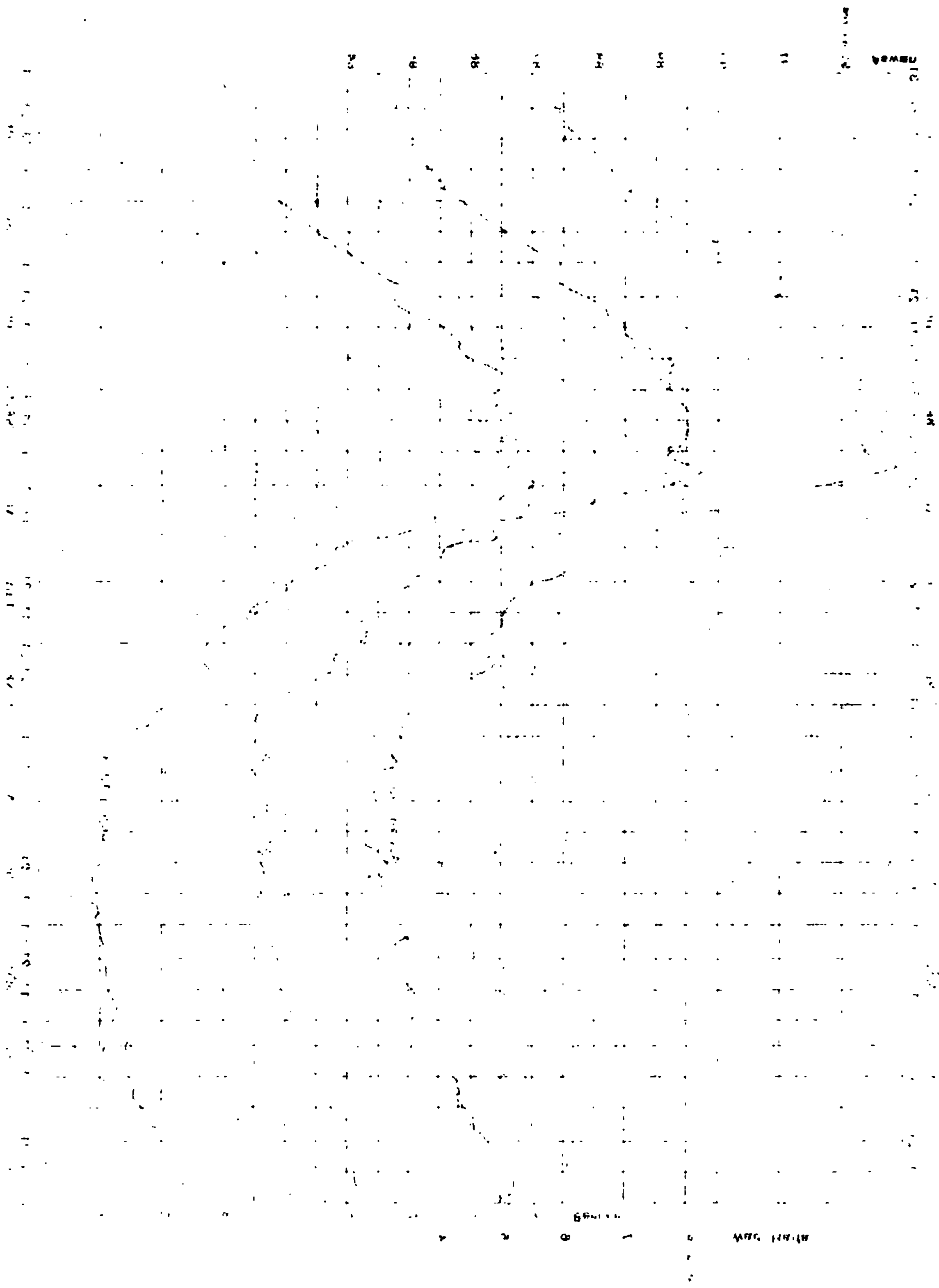
[1] Chélu, "Le Nil, le Soudan, l'Egypte," p. 38, Paris, 1891.
[2] This value is too high.
[3] Much too low, as in 1876 the Nile was above the average in September.
[4] Pet. Mitt., 1883, p. 268.

PLATE XXXVIa.

GAUGE READINGS NILE 1903.



Survey Dept. Cairo.



Area of section = 607·3 square metres, and the velocity = 100 metres in 4 minutes 30 seconds, or 0·27 metre per second. Discharge = 225 cubic metres per second.

Collecting the various results, we obtain the following table :—

Date	White Nile, cubic metres per second	Blue Nile, cubic metres per second	Combined Nile, cubic metres per second
March 4-5, 1822	297	158	..
July 26-30, 1827	6044	6247	12,000
July 5, 1848	3000	3700	..
October 23-25, 1851	1410	2749	4,500
March, 1876	369	..	..
Low stage, 1876	..	198	..
June "	1050	..	..
Flood "	..	4398	..
September "	4351	..	..
December "	2720	..	..
April, 1883	750	225	..

but, as will be seen on comparison with more recent measurements, the older ones are of small value.

During the 13 months (November 1902-November 1903) 19 measurements were made of the volume discharged by the Nile downstream of Khartoum and the results are given on page 277. From November to July these were made at Kerreri 20 kilometres below Khartoum where the river flows in a wide shallow trough of which only one half is occupied at low stage. In August, September, and October, the measurements were made just above the Shabluka gorge 80 kilometres below Khartoum where the river is in a single deep channel.

DISCHARGES OF THE COMBINED BLUE AND WHITE NILE.

Kerreri.

Date	Width [1]	Mean depth	Sectional area	Mean velocity	Discharge		Khartoum. gauge on date of observation.
	m.	m.	m^2	m. p. s.	$m.^3$ p. s.		m.
1902							
Nov. 8	341 E.	6·53	2295	1·178	2991	3390	2·90
	488 W.	1·48	744	0·538	399		
Nov. 17	304 E.	5·54	1768	1·062	2119	2369	2·34
	460 W.	1·06	501	0·532	250		
Dec. 8	304 E.	5·28	1722	1·183	2039	2172	1·88
	283 W.	1·11	317	0·420	133		

[1] E = east channel. W = west channel.

DISCHARGES OF THE COMBINED BLUE AND WHITE NILE—(*continued*).

Kerreri.

Date	Width [1]	Mean depth	Sectional area	Mean Velocity	Discharge	Khartoum gauge on date of observation
1903	m.	m.	m²	m. p. s.	m³ p. s.	m.
Feb. 3	290	3·51	1025	0·764	814	0·62
Mar. 2	282	2·96	884	0·751	696	0·21
„ 30	275	2·83	751	0·680	490	−0·11
May 24	278	2·78	812	0·750	621	+0·12
June 20	311	4·75	1548	1·322	1982	1·85
July 4	315 E.	4·75	1616	1·203	2047 } 2225	1·95
	288 W.	1·11	308	0·562	178	
„ 18	365 E.	5·60	2125	1·376	3012 } 3416	2·75
	345 W.	1·63	537	0·740	404	
			Shabluka.			
Aug. 6	374	8·96	3554	1·976	6981	4·75
„ 22	388	11·00	4318	2·185	9850	5·95
Sept. 2	392	12·67	5318	1·845	10457	6·30
„ 16	389	13·10	5262	1·805	10433	5·95
„ 30	386	13·10	4905	1·632	8203	5·55
Oct. 14	376	11·90	4610	1·255	6164	4·70
„ 28	368	10·70	4153	1·178	4948	4·10
			Kerreri.			
Nov. 14	403 E.	6·00	2360	0·823	2968 } 3613	3·05
	370 W.	2·18	792	0·802	645	
Dec. 1	368 E.	4·91	1808	0·782	1823 } 2353	2·40
	341 W.	1·86	633	0·804	530	

At Berber gauge readings were made in 1880-83 from June 11 until October 9, and again from 1900 to the present time; the highest and lowest readings being :

Year	Lowest gauge	Reading	Highest gauge	Reading	Range
	metres	date	metres	date	metres
1880	6·88	June 12	13·95	Aug. 28	6·07
1881	6·73	„ 10	14·56	Sept. 15	7·83
1882	5·65	„ 11	12·89	Aug. 26	7·24
1883	6·64	„ 11	14·13	Sept. 11	7·49
Readings were resumed on May 4 1900 but are not referable to the earlier ones.					
1900	0·41	May 4 [2]	7·67	Aug. 17	7·26
1901	0·63	April 15	7·87	„ 31	7·24
1902	0·61	„ 30	7·05	Sept. 11	6·44
1903	0·72	May 9	8·10	Aug. 22	7·38
1904	0·94	„ 15	6·98	Sept. 7	6·04
1905	0·67	„ 14	7·33	„ 12	6.66

[1] E = east channel. W = west channel.
[2] First observation taken.

The range given for the years 1880-1883 is less than the true one as on the dates (after June 10) that the readings were made the river at Khartoum had already been rising for some time. The date of the highest flood often precedes that at Khartoum on account of the Atbara reaching its maximum before the Blue Nile. Its rapid rise, pouring in a considerable volume of water, which in good years probably reaches 4000 cubic metres per second, raises the water level and reduces the water slope up-stream of the junction, so that in a recent flood it was found to be about 1 in 12,000.

The volume of the Nile is here at its maximum after receiving its last tributary the Atbara, and in 1876[1] discharges were measured at Berber but the loss of all information about the method of determining the volume passing, the frequency of the observations etc. makes them of small value:

	Million of cubic metres per day	Mean discharge in cubic metres per second
Jan. 15—Feb. 15..	1,578·5	589
Feb. 15—Mar. 15..	1,367·3	545
Mar. 15—April 15..	2,649·7	978
April 15—May 15..	3,559·9	1,374
May 15—June 15..	7,203·7	2,700
June 15—July 15..	10,873·0	4,192
July 15—Aug 15..	22,707·7	8,470
Aug. 15—Sep. 15..	28,682·7	10,069
Sept. 15—Oct. 15..	19,258·8	7,430
Oct. 15—Nov. 15..	16,409·0	6,130
Nov. 15—Dec. 15..	9,590·0	3,700
Dec. 15—Jan. 15..	4,354·0	1,626

In comparing them with those taken at Khartoum (Ch. VI) the values, especially those for March, April, May and June, are far too high and those of the flood diverge greatly from those derived from the gauge readings at Aswan.

From Berber to Abu Hamed recent levelling gives 1 in 7,000 as the average slope at low stage the steepest being 1 in 1,840 for the 13 kilometres which comprise the fifth Cataract.

Below Berber no measurements have been made until Sarras is reached except at Kaibar cataract where Gottberg[2] gives the low stage discharge in 1857 as 525 cubic metres per second.

[1] Chélu, cit. loc., p. 37.

[2] Loc. cit., p. 53.

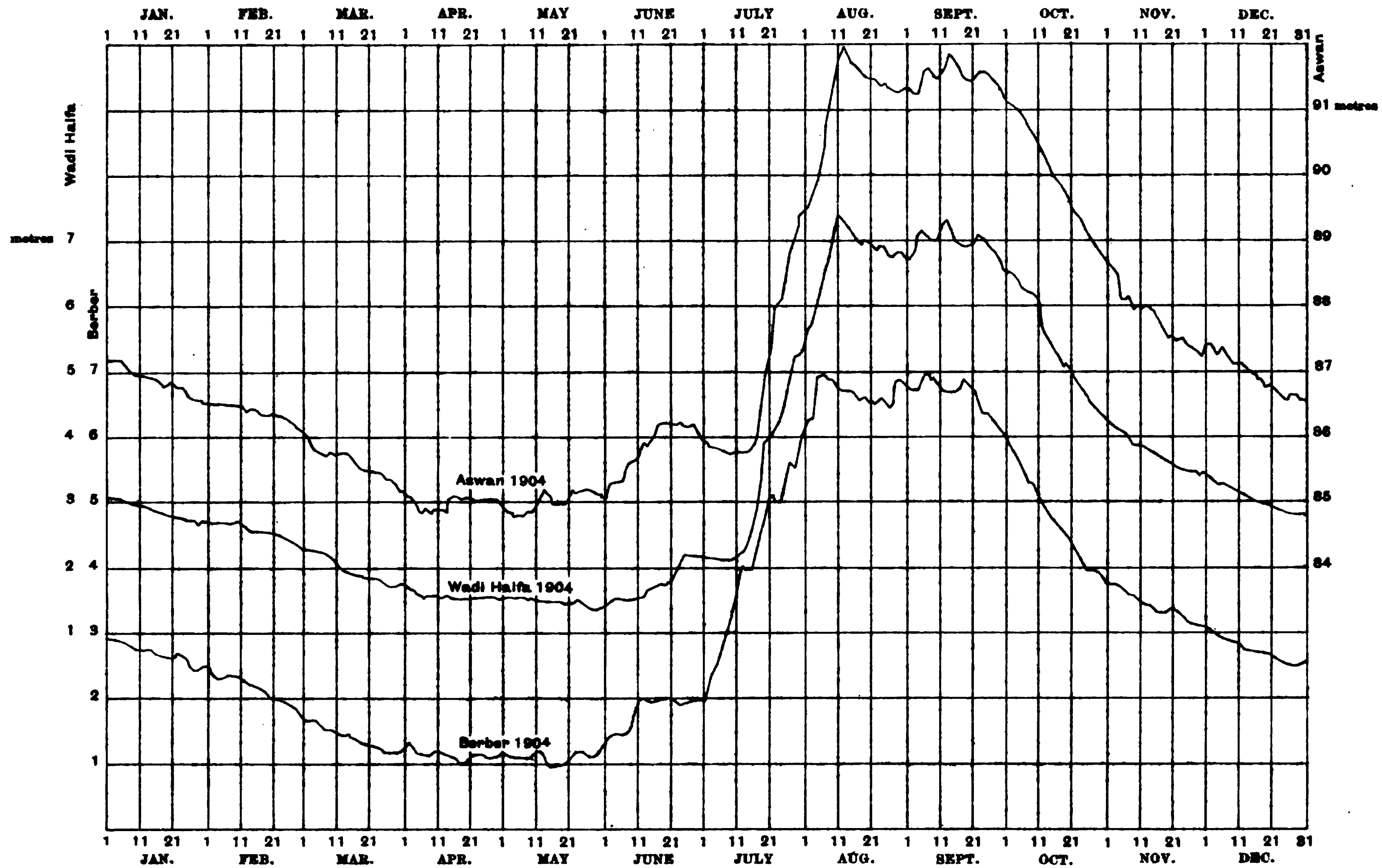
At Sarras in June 1905 a gauging station was established and a series of discharges were taken at a point 48 kilometres from Wadi Halfa where the river passed though a rocky and somewhat narrow channel (Plate XXXIV*b*). The work of this first season was mainly of an experimental character as the necessary equipment for work in such deep and rapid water was not ready before the flood rose. Observations were taken from May 14 until August 20 when the steel hawser was carried away and could not be replaced until the river had fallen. After July 21 it was found impossible to sound accurately with the ordinary sounding line and the wire sounding apparatus not having been received, the depth after this date was obtained by adding to those measured on July 21 the rise of the river as recorded on the gauge. This assumes that the bed did not change but this is very doubtful as although the section is wholly in rock the passage of sand waves down the river must change the area of the section from time; another year's work is necessary to show their value. Work was recommenced on December 7 and continued regularly from that date.

VOLUME DISCHARGED AT SARRAS 50 KILOMETRES UP-STREAM OF WADI-HALFA.

Date	Width	Mean depth	Sectional Area	Mean Velocity	Discharge	Gauge	
						Sarras	Halfa 1 day later
1905	metres	metres	metres	m. p. s.	m³ p. s.	metres	m.
May 14.. .	165	12·9	1982	0·311	617	0·63	1·00
„ 31.. ..	165	12·5	2066	0·291	601	0·57	0·97
June 8.. ..	165	12·9	2125	0 281	597	0·52	0·92
„ 22.. ..	165	13·4	2206	0·313	691	0·83	1·11
July 4.. ..	165	13·7	2262	0·373	853	1·52	1·51
„ 8.. ..	165	13·7	2268	0·439	997	1·95	1·75
„ 11.. ..	168	14·0	2317	0·449	1041	2·16	1·85
July 13.. ..	168	13·9	2342	0·494	1156	2·29	1·88
„ 18.. ..	168	14·1	2366	0·565	1338	3·10	2·36
„ 21.. ..	168	15·2	2562	0·554	1439	3·38	2·49
„ 27.. ..	226	*	2916	0·656	1915	4·15	2·96
Aug. 1.. ..	241	*	3198	0·796	2572	5·66	3·92
„ 8.. ..	241	*	3567	0·930	3308	6·30	4·20
„ 11.. ..	242	*	3536	0·990	3512	6·65	4·58
„ 14.. ..	246	*	3724	1·129	4207	7·42	5·06
„ 17.. ..	249	*	4053	1·369	5550	8·56	5·63
„ 20.. ..	256	*	4564	1·660	7577	9·75	6·87
Dec. 7.. .	173	*	2754	0·770	2114	4·65	3·08
„ 10.. ..	171	16·1	2687	0·790	2132	4·56	3·03
„ 13.. ..	171	16·4	2726	0·720	2021	4·48	2·98
„ 16.. ..	170	16·3	2712	0·740	2020	4·46	2·97
„ 20.. ..	170	16·1	2677	0·710	1904	4·38	2·92
„ 22.. ..	170	16·0	2668	0·710	1898	4·36	2·88

* On these dates sounding was not practicable so discharge is calculated on an approximate mean depth obtained by adding rise of water level to the mean depth found on July 21.

GAUGE READINGS NILE 1904



Survey Dept. Cairo.

VOLUME DISCHARGED AT SARRAS 50 KILOMETRES UP-STREAM OF WADI-HALFA (*continued*).

Date	Width	Mean Depth	Sectional Area	Mean Velocity	Discharge	Gauge	
						Sarras	Halfa 1 day later
1906	metres	metres	metres	m. p. s.	m^3 p. s.	metres	m.
Jan. 1.. ..	170	15·5	2579	0·630	1570	3·92	2·62
„ 6.. ..	170	15·4	2566	0·610	1567	3·81	2·56
„ 9.. ..	168	15·4	2545	0·560	1431	3·70	2·50
„ 11.. ..	168	15·4	2543	0·590	1525	3·66	2·48
„ 14.. ..	168	15·2	2524	0·610	1548	3·61	2·45
„ 17.. ..	168	15·2	2521	0·570	1441	3·52	2·43
„ 20.. ..	168	15·1	2507	0·560	1403	3·46	2·38
„ 22.. ..	168	15·0	2495	0·530	1323	3·35	2·32
„ 25.. ..	168	15·0	2491	0·570	1423	3·32	2·32
„ 27.. ..	168	15·0	2495	0·550	1362	3·32	2·30
„ 30.. ..	167	14·9	2466	0·540	1323	3·27	2·26
Feb. 1.. ..	167	14·8	2461	0·540	1316	3·21	2·25
„ 5.. ..	166	14·5	2414	0·501	1210	3·05	2·17
„ 7.. ..	166	14·45	2403	0·534	1210	2·93	2·11
„ 9.. ..	165	14·42	2399	0·479	1149	2·90	2·03
„ 11.. ..	165	14·69	2416	0·471	1137	2·86	2·02

The present river gauge at Wadi Halfa was built in 1890, and daily readings exist from the beginning of January, 1890, to the present time. Now that the reservoir at Aswan has been constructed, the readings of the gauge on the island of Elephantine no longer represent the true rise and fall of the river and consequently the Wadi Halfa gauge is of increased importance. The mean 5-day readings are given in the following table as well as the differences of each such period from the mean for the 15 years in order to show readily when the river supply was above or below the normal. In consequence of the great variation of the river level from year to year the mean values obtained from 15 years observations only give an approximation to the normal levels, and the probable error in them varies from about 0·20 metre at low stage to 0·60 or 0·70 metre at flood stage, so that a considerably longer series is necessary to obtain mean values of a higher accuracy. This is the first gauge below Khartoum which has been observed daily for a series of years, and which therefore records the level of the whole volume of the Nile; this in the flood season is the total run off from the Abyssinian plateau since, as we have seen, the contribution of the White Nile is negligible.

Latitude 21° 54′ 49″ N.
Longitude 31° 19′ 4″·1 E.

WADI HALFA GAUGE

5 DAY MEANS (IN METRES).

Zero of gauge 116^{m}.7 above mean sea level at Alexandria.

DATE		1890	1891	1892	1893	1894	1895	1896	1897	1898	1899	1900	1901	1902	1903	1904	15 Years.
Jan.	1–5	2·71	3·41	3·37	3·96	3·42	4·10	3·87	4·14	3·06	3·62	1·88	2·74	2·63	2·75	3·09	3·25
	6–10	2·65	3·30	3·22	3·89	3·35	4·00	3·76	4·02	2·96	3·50	1·79	2·64	2·50	2·64	2·99	3·15
	11–15	2·59	3·21	3·15	3·82	3·31	3·96	3·68	3·87	2·92	3·48	1·69	2·55	2·34	2·58	2·91	3·07
	16–20	2·52	3·13	3·04	3·77	3·26	3·84	3·62	3·74	2·87	3·37	1·63	2·47	2·20	2·50	2·83	2·99
	21–25	2·40	3·03	2·93	3·70	3·18	3·78	3·56	3·73	2·83	3·33	1·57	2·36	2·05	2·40	2·74	2·91
	26–31	2·25	2·91	2·83	3·67	3·07	3·69	3·51	3·62	2·74	3·29	1·51	2·22	1·96	2·29	2·66	2·81
Feb.	1–5	2·03	2·70	2·69	3·59	2·95	3·62	3·42	3·52	2·71	3·25	1·44	2·12	1·88	2·15	2·64	2·71
	6–10	1·90	2·52	2·55	3·47	2·82	3·58	3·39	3·45	2·62	3·20	1·40	2·03	1·80	2·02	2·61	2·62
	11–15	1·76	2·34	2·40	3·46	2·70	3·55	3·31	3·36	2·47	3·15	1·36	1·94	1·76	1·89	2·56	2·53
	16–20	1·67	2·20	2·24	3·41	2·56	3·51	3·27	3·26	2·37	3·11	1·34	1·90	1·71	1·79	2·53	2·46
	21–25	1·54	2·05	2·10	3·35	2·42	3·45	3·16	3·17	2·21	3·05	1·30	1·82	1·64	1·66	2·44	2·36
	26–28/29	1·46	1·90	1·97	3·29	2·32	3·40	3·02	3·06	2·05	3·04	1·30	1·76	1·59	1·63	2·34	2·28
Mar.	1–5	1·38	1·83	1·86	3·26	2·24	3·34	2·94	2·99	1·96	2·99	1·23	1·69	1·56	1·56	2·25	2·21
	6–10	1·35	1·67	1·78	3·20	2·12	3·26	2·86	2·93	1·89	2·91	1·18	1·61	1·51	1·49	2·14	2·13
	11–15	1·29	1·55	1·67	3·23	2·02	3·18	2·74	2·86	1·79	2·84	1·11	1·53	1·43	1·42	1·97	2·04
	16–20	1·20	1·52	1·55	3·18	1·92	3·14	2·57	2·72	1·74	2·76	1·06	1·48	1·38	1·41	1·89	1·97
	21–25	1·16	1·44	1·51	3·18	1·84	3·06	2·48	2·55	1·65	2·67	1·06	1·41	1·36	1·31	1·80	1·90
	26–31	1·11	1·42	1·40	3·16	1·78	3·01	2·37	2·43	1·59	2·56	1·00	1·34	1·32	1·24	1·69	1·83
April	1–5	1·02	1·41	1·31	3·17	1·73	2·91	2·30	2·34	1·51	2·42	0·96	1·30	1·29	1·21	1·61	1·77
	6–10	0·93	1·32	1·23	3·13	1·70	2·84	2·24	2·19	1·47	2·30	0·97	1·24	1·29	1·13	1·58	1·70
	11–15	0·85	1·32	1·17	3·00	1·67	2·78	2·17	2·13	1·45	2·16	0·95	1·20	1·32	1·08	1·57	1·65
	16–20	0·80	1·25	1·13	2·86	1·63	2·72	2·10	2·09	1·38	2·09	0·95	1·20	1·30	1·11	1·53	1·61
	21–25	0·76	1·18	1·06	2·62	1·59	2·59	2·03	2·01	1·35	2·02	0·97	1·14	1·23	1·03	1·54	1·54
	26–30	0·70	1·15	1·00	2·40	1·53	2·52	2·04	2·01	1·29	1·93	0·97	1·07	1·23	1·02	1·52	1·49
May	1–5	0·64	1·19	0·97	2·24	1·52	2·46	1·97	1·98	1·25	1·87	0·98	1·05	1·20	0·97	1·51	1·45
	6–10	0·62	1·15	0·95	2·03	1·54	2·38	1·92	1·96	1·26	1·81	0·90	1·11	1·16	0·98	1·52	1·42
	11–15	0·62	1·15	0·93	1·91	1·61	2·40	2·02	1·90	1·23	1·76	0·95	1·26	1·22	0·98	1·47	1·43
	16–20	0·63	1·23	0·97	1·82	1·66	2·43	1·99	1·89	1·19	1·67	0·94	1·33	1·25	1·00	1·44	1·43
	21–25	0·64	1·33	0·88	1·74	1·66	2·44	1·92	1·88	1·17	1·53	0·95	1·38	1·20	0·98	1·44	1·41
	26–31	0·65	1·33	0·84	1·70	1·67	2·46	1·88	1·89	1·16	1·47	1·08	1·35	1·16	0·99	1·36	1·40
June	1–5	0·71	1·52	0·88	1·62	1·66	2·40	1·89	1·91	1·18	1·52	1·06	1·29	1·17	0·99	1·45	1·42
	6–10	0·82	2·17	0·94	1·56	1·57	2·34	1·83	1·91	1·11	1·54	1·17	1·24	1·30	1·03	1·49	1·47
	11–15	0·93	2·53	0·96	1·54	1·57	2·32	1·91	1·93	1·12	1·65	1·33	1·24	1·28	1·39	1·61	1·55
	16–20	1·15	2·58	1·05	1·60	1·76	2·29	1·99	2·24	1·11	1·85	1·42	1·37	1·33	1·91	1·76	1·69
	21–25	1·37	2·67	1·30	1·68	2·49	2·35	2·07	2·64	1·38	1·87	1·52	1·58	1·65	2·21	2·06	1·92
	26–30	1·47	2·59	1·56	1·78	3·05	2·47	2·08	2·81	2·09	1·90	1·58	1·85	1·84	2·39	2·19	2·11

July	1– 5	2·19	2·63	1·75	2·00	3·06	3·07	2·27	2·87	2·14	2·05	1·65	2·23	1·85	2·72	2·15	2·31
	6–10	2·54	2·83	2·44	2·24	3·14	3·45	2·80	2·95	2·13	2·28	2·07	2·66	2·15	2·75	2·13	2·57
	11–15	2·91	2·86	2·79	2·57	3·54	3·79	3·60	3·30	2·35	2·96	2·63	3·04	2·42	2·88	2·26	2·93
	16–20	3·32	3·04	3·55	3·22	4·48	4·54	4·62	3·83	2·94	3·65	3·18	3·58	2·76	3·28	3·27	3·55
	21–25	3·94	3·92	4·52	3·90	5·12	5·34	5·39	4·00	3·42	3·90	3·43	4·08	3·09	3·68	4·13	4·12
	26–31	5·91	4·98	5·66	5·46	5·59	6·56	5·54	4·26	3·86	4·19	3·86	4·45	3·44	4·05	5·02	4·86
Aug.	1– 5	6·64	5·75	6·74	6·26	6·50	7·90	6·08	5·00	5·84	4·53	5·62	5·07	3·74	4·05	5·65	5·73
	6–10	7·30	6·87	7·04	7·12	7·59	8·21	6·16	6·34	7·60	5·55	7·30	6·60	4·20	4·92	6·72	6·63
	11–15	8·02	7·24	7·08	7·20	7·99	8·19	6·75	6·95	7·61	6·18	7·76	7·15	5·05	6·20	7·26	7·11
	16–20	8·28	7·51	7·60	7·58	8·17	8·49	7·72	7·05	8·02	6·06	8·01	7·94	5·55	7·04	6·99	7·47
	21–25	8·65	7·69	8·53	7·70	8·84	8·73	7·89	7·44	8·44	6·46	7·98	7·91	5·89	7·93	6·88	7·80
	26–31	8·73	7·74	8·59	7·59	8·93	8·50	8·53	7·86	8·60	6·78	8·00	7·70	6·34	7·87	6·76	7·90
Sept.	1– 5	8·74	8·00	8·70	7·46	8·74	8·59	8·67	7·86	8·46	6·86	7·74	7·88	6·65	7·81	6·87	7·94
	6–10	8·47	7·99	8·95	7·60	8·57	8·68	8·54	7·74	8·38	6·61	7·31	7·98	6·85	8·03	7·00	7·91
	11–15	8·42	7·99	9·00	7·80	8·79	8·42	8·43	7·61	8·21	6·44	7·18	7·80	7·01	8·06	7·23	7·89
	16–20	8·31	7·95	8·99	7·64	8·83	7·95	8·35	7·70	8·14	6·48	7·54	7·75	7·06	7·86	6·95	7·83
	21–25	8·15	7·93	8·86	7·78	8·60	7·50	8·09	7·60	7·93	6·27	7·48	7·47	6·96	7·70	7·02	7·69
	26–30	7·85	7·62	8·68	7·60	8·55	7·03	7·77	7·36	7·72	5·95	7·34	6·96	6·74	7·72	6·78	7·44
Oct.	1– 5	7·62	7·19	8·44	7·46	8·46	6·72	7·48	6·99	7·67	5·66	7·13	6·39	6·46	7·48	6·47	7·17
	6–10	7·54	6·90	8·05	7·58	8·32	6·49	7·13	6·68	7·40	5·16	6·88	5·86	6·41	7·08	6·21	6·91
	11–15	7·42	6·72	7·75	7·33	8·06	6·45	6·74	6·32	7·06	4·72	6·31	5·37	6·20	6·88	5·70	6·60
	16–20	7·05	6·83	7·45	6·87	7·75	6·14	6·45	6·00	6·79	4·33	5·72	5·04	5·82	6·59	5·17	6·27
	21–25	6·77	6·54	7·11	6·41	7·31	5·90	6·32	5·65	6·56	4·00	5·13	4·77	5·24	6·07	4·80	5·91
	26–31	6·48	6·13	6·66	6·01	6·75	5·66	6·12	5·16	6·14	3·73	4·62	4·49	4·81	5·89	4·45	5·54
Nov.	1– 5	5·93	5·77	6·08	5·70	6·30	5·39	5·95	4·76	5·65	3·47	4·23	4·28	4·51	5·65	4·11	5·19
	6–10	5·36	5·64	5·57	5·28	5·83	5·18	5·61	4·41	5·31	3·22	3·96	4·05	4·27	5·20	3·93	4·85
	11–15	4·99	5·44	5·28	4·95	5·48	4·98	5·26	4·12	5·02	3·09	3·74	3·84	4·01	4·84	3·81	4·59
	16–20	4·75	5·17	5·01	4·72	5·22	4·78	5·30	3·94	4·83	2·96	3·56	3·64	3·80	4·43	3·66	4·38
	21–25	4·49	4·88	4·78	4·54	5·05	4·68	5·76	3·76	4·58	2·87	3·44	3·49	3·57	4·14	3·49	4·23
	26–30	4·27	4·54	4·57	4·32	4·84	4·57	5·80	3·64	4·46	2·76	3·33	3·32	3·40	3·91	3·42	4·08
Dec.	1– 5	4·09	4·09	4·45	4·10	4·68	4·50	5·53	3·56	4·32	2·64	3·20	3·16	3·33	3·75	3·33	3·92
	6–10	4·01	3·99	4·30	3·98	4·57	4·47	5·33	3·44	4·24	2·52	3·13	3·06	3·23	3·56	3·21	3·80
	11–15	3·94	3·94	4·25	3·85	4·47	4·42	5·00	3·37	4·20	2·39	3·02	3·01	3·14	3·45	3·07	3·70
	16–20	3·79	3·79	4·12	3·73	4·43	4·31	4·71	3·32	4·04	2·26	2·96	2·95	3·03	3·35	2·97	3·58
	21–25	3·61	3·61	4·08	3·64	4·33	4·16	4·47	3·21	3·88	2·10	2·88	2·86	2·93	3·25	2·88	3·46
	26–31	3·50	3·50	4·02	3·53	4·18	4·02	4·29	3·13	3·73	1·98	2·81	2·76	2·82	3·13	2·81	3·35
Yearly	Mean*	3·65	3·84	3·93	4·22	4·31	4·54	4·37	3·98	3·81	3·37	3·15	3·33	3·07	3·49	3·44	3·77
	Max.†	8·96	8·06	9·04	7·90	8·96	8·88	8·76	8·00	8·72	6·92	8·06	8·08	7·15	8·20	7·36	8·20
	Min.‡	0·62	1·13	0·83	1·52	1·52	2·28	1·82	1·86	1·09	1·46	0·89	1·04	1·13	0·95	1·35	1·30

* Mean derived from daily readings. † Highest reading recorded in year. ‡ Lowest reading recorded in year.

Latitude 21° 54′ 49″ N.
Longitude 31° 19′ 4″.1 E.

WADI HALFA GAUGE

DIFFERENCES FROM MEANS OF 15 YEARS 1890-1904 (IN METRES).

Zero of gauge 116m. 7above mean sea level at Alexandria.

DATE		1890	1891	1892	1893	1894	1895	1896	1897	1898	1899	1900	1901	1902	1903	1904	Mean 15 years 1890-1904
Jan.	1- 5	-0·54	+0·16	+0·12	+0·71	+0·17	+0·85	+0·62	+0·89	-0·19	+0·37	-1·37	-0·51	-0·62	-0·50	-0·16	3·25
	6-10	-0·50	+0·15	+0·07	+0·74	+0·20	+0·85	+0·61	+0·87	-0·19	+0·35	-1·36	-0·51	-0·65	-0·51	-0·16	3·15
	11-15	-0·48	+0·14	+0·08	+0·75	+0·24	+0·89	+0·61	+0·80	-0·15	+0·41	-1·38	-0·52	-0·73	-0·49	-0·16	3·07
	16-20	-0·47	+0·14	+0·05	+0·78	+0·27	+0·85	+0·63	+0·75	-0·12	+0·38	-1·36	-0·52	-0·79	-0·49	-0·16	2·99
	21-25	-0·51	+0·12	+0·02	+0·79	+0·27	+0·87	+0·65	+0·82	-0·08	+0·42	-1·34	-0·55	-0·86	-0·51	-0·17	2·91
	26-31	-0·56	+0·10	+0·02	+0·86	+0·26	+0·88	+0·70	+0·81	-0·07	+0·48	-1·30	-0·59	-0·85	-0·52	-0·15	2·81
Feb.	1- 5	-0·68	-0·01	-0·02	+0·88	+0·24	+0·91	+0·71	+0·81	0·00	+0·54	-1·27	-0·59	-0·83	-0·56	-0·07	2·71
	6-10	-0·72	-0·10	-0·07	+0·85	+0·20	+0·96	+0·77	+0·83	0·00	+0·58	-1·22	-0·59	-0·82	-0·60	-0·01	2·62
	11-15	-0·77	-0·19	-0·13	+0·93	+0·17	+1·02	+0·78	+0·83	-0·06	+0·62	-1·17	-0·59	-0·77	-0·64	+0·03	2·53
	16-20	-0·79	-0·26	-0·22	+0·95	+0·10	+1·05	+0·81	+0·80	-0·09	+0·65	-1·12	-0·56	-0·75	-0·67	+0·07	2·46
	21-25	-0·82	-0·31	-0·26	+0·99	+0·06	+1·09	+0·80	+0·81	-0·15	+0·69	-1·06	-0·54	-0·72	-0·70	+0·08	2·36
	26-28/29	-0·82	-0·38	-0·31	+1·01	+0·04	+1·12	+0·74	+0·78	-0·23	+0·76	-0·98	-0·52	-0·69	-0·65	+0·06	2·28
Mar.	1- 5	-0·83	-0·38	-0·35	+1·05	+0·03	+1·13	+0·73	+0·78	-0·25	+0·78	-0·98	-0·52	-0·65	-0·65	+0·04	2·21
	6-10	-0·78	-0·46	-0·35	+1·07	-0·01	+1·13	+0·73	+0·80	-0·24	+0·78	-0·95	-0·52	-0·62	-0·64	+0·01	2·13
	11-15	-0·75	-0·49	-0·37	+1·19	-0·02	+1·14	+0·70	+0·82	-0·25	+0·80	-0·93	-0·51	-0·61	-0·62	-0·07	2·04
	16-20	-0·77	-0·45	-0·42	+1·21	-0·05	+1·17	+0·60	+0·75	-0·23	+0·79	-0·91	-0·49	-0·59	-0·56	-0·08	1·97
	21-25	-0·74	-0·46	-0·39	+1·28	-0·06	+1·16	+0·58	+0·65	-0·25	+0·77	-0·84	-0·49	-0·54	-0·59	-0·10	1·90
	26-31	-0·72	-0·41	-0·43	+1·33	-0·05	+1·18	+0·54	+0·60	-0·24	+0·73	-0·83	-0·49	-0·51	-0·59	-0·14	1·83
April	1- 5	-0·75	-0·36	-0·46	+1·40	-0·04	+1·14	+0·53	+0·57	-0·25	+0·65	-0·81	-0·47	-0·48	-0·56	-0·16	1·77
	6-10	-0·77	-0·38	-0·47	+1·43	0·00	+1·14	+0·54	+0·49	-0·23	+0·60	-0·73	-0·46	-0·41	-0·57	-0·12	1·70
	11-15	-0·80	-0·33	-0·48	+1·35	+0·02	+1·13	+0·52	+0·48	-0·20	+0·51	-0·70	-0·45	-0·33	-0·57	-0·08	1·65
	16-20	-0·81	-0·36	-0·48	+1·25	+0·02	+1·11	+0·49	+0·48	-0·23	+0.48	-0·66	-0·41	-0·31	-0·50	-0·08	1·61
	21-25	-0·78	-0·36	-0·48	+1·08	+0·05	+1·05	+0·49	+0·47	-0·19	+0·48	-0·57	-0·40	-0·31	-0·51	0·00	1·54
	26-30	-0·79	-0·34	-0·49	+0·91	+0·04	+1·03	+0·55	+0·52	-0·20	+0·44	-0·52	-0·42	-0·26	-0·47	+0·03	1·49
May	1- 5	-0·81	-0·26	-0·48	+0·79	+0·07	+1·01	+0·52	+0·53	-0·20	+0·42	-0·47	-0·40	-0·25	-0·48	+0·06	1·45
	6-10	-0·80	-0·27	-0·47	+0·61	+0·12	+0·96	+0·50	+0·54	-0·16	+0·39	-0·52	-0·31	-0·26	-0·44	+0·10	1·42
	11-15	-0·81	-0·28	-0·50	+0·48	+0·18	+0·97	+0·59	+0·47	-0·20	+0·33	-0·48	-0·17	-0·21	-0·45	+0·04	1·43
	16-20	-0·80	-0·20	-0·45	+0·39	+0·22	+1·00	+0·56	+0·46	-0·24	+0·24	-0·49	-0·10	-0·18	-0·43	+0·01	1·43
	21-25	-0·77	-0·08	-0·53	+0·33	+0·25	+1·03	+0·51	+0·47	-0·24	+0·12	-0·46	-0·03	-0·21	-0·43	+0·03	1·41
	26-31	-0·75	-0·07	-0·56	+0·30	+0·27	+1·06	+0·48	+0·49	-0·24	+0·07	-0·32	-0·05	-0·24	-0·41	-0·04	1·40
June	1- 5	-0·71	+0·10	-0·54	+0·20	+0·24	+0·98	+0·47	+0·49	-0·24	+0·10	-0·36	-0·13	-0·25	-0·43	+0·03	1·42
	6-10	-0·65	+0·70	-0·53	+0·09	+0·10	+0·87	+0·36	+0·44	-0·36	+0·07	-0·30	-0·23	-0·17	-0·44	+0·02	1·47
	11-15	-0·62	+0·98	-0·59	-0·01	+0·02	+0·77	+0·36	+0·38	-0·43	+0·10	-0·22	-0·31	-0·27	-0·16	+0·06	1·55
	16-20	-0·54	+0·89	-0·63	-0·09	+0·07	+0·60	+0·30	+0·55	-0·58	+0·16	-0·27	-0·32	-0·36	+0·22	+0·07	1·69
	21-25	-0·55	+0·75	-0·62	-0·24	+0·57	+0·43	+0·15	+0·72	-0·54	-0·05	-0·40	-0·34	-0·27	+0·29	+0·14	1·92
	26-30	-0·64	+0·48	-0·55	-0·33	+0·94	+0·36	-0·03	+0·70	-0·02	-0·21	-0·53	-0·26	-0·27	+0·28	+0·08	2·11

July	1– 5	−0·12	+0·32	−0·55	−0·31	+0·75	+0·76	−0·04	+0·56	−0·17	−0·26	−0·66	−0·08	−0·46	+0·41	−0·16	2·31
	6–10	−0·03	+0·26	−0·13	−0·33	+0·57	+0·88	+0·23	+0·38	−0·44	−0·29	−0·50	+0·09	−0·42	+0·18	−0·44	2·57
	11–15	−0·02	−0·07	−0·14	−0·36	+0·61	+0·86	+0·67	+0·37	−0·58	+0·03	−0·30	+0·11	−0·51	−0·05	−0·67	2·93
	16–20	−0·23	−0·51	0·00	−0·33	+0·93	+0·99	+1·07	+0·28	−0·61	+0·10	−0·37	+0·03	−0·79	−0·27	−0·28	3·55
	21–25	−0·18	−0·20	+0·40	−0·22	+1·00	+1·22	+1·27	−0·12	−0·70	−0·22	−0·69	−0·04	−1·03	−0·44	+0·01	4·12
	26–31	+1·05	+0·12	+0·80	+0·60	+0·73	+1·70	+0·68	−0·60	−1·00	−0·67	−1·00	−0·41	−1·42	−0·81	+0·16	4·86
Aug.	1– 5	+0·91	+0·02	+1·01	+0·53	+0·77	+2·17	+0·35	−0·73	+0·11	−1·20	−0·11	−0·66	−1·99	−1·07	−0·08	5·73
	6–10	+0·67	+0·24	+0·41	+0·49	+0·96	+1·58	−0·47	−0·29	+0·97	−1·08	+0·67	−0·03	−2·43	−1·71	+0·09	6·63
	11–15	+0·91	+0·13	−0·03	+0·09	+0·88	+1·08	−0·36	−0·16	+0·50	−0·93	+0·65	+0·04	−2·06	−0·91	+0·15	7·11
	16–20	+0·81	+0·04	+0·13	+0·11	+0·70	+1·02	+0·25	−0·42	+0·55	−1·41	+0·54	+0·47	−1·92	−0·43	−0·48	7·47
	21–25	+0·85	−0·11	+0·73	−0·10	+1·04	+0·93	+0·09	−0·36	+0·64	−1·34	+0·18	+0·11	−1·91	+0·13	−0·92	7·80
	26–31	+0·83	−0·16	+0·69	−0·31	+1·03	+0·60	+0·63	−0·04	+0·70	−1·12	+0·10	−0·20	−1·56	−0·03	−1·14	7·90
Sept.	1– 5	+0·80	+0·06	+0·76	−0·48	+0·80	+0·65	+0·73	−0·08	+0·52	−1·08	−0·20	−0·06	−1·29	−0·13	−1·07	7·94
	6–10	+0·56	+0·08	+1·04	−0·31	+0·66	+0·77	+0·63	−0·17	+0·47	−1·30	−0·60	+0·07	−1·06	+0·12	−0·91	7·91
	11–15	+0·53	+0·10	+1·11	−0·09	+0·90	+0·53	+0·54	−0·28	+0·32	−1·45	−0·71	−0·09	−0·88	+0·17	−0·66	7·89
	16–20	+0·48	+0·12	+1·16	−0·19	+1·00	+0·12	+0·52	−0·13	+0·31	−1·35	−0·29	−0·08	−0·77	+0·03	−0·88	7·83
	21–25	+0·46	+0·24	+1·17	+0·09	+0·91	−0·19	+0·40	−0·09	+0·24	−1·42	−0·21	−0·22	−0·73	+0·01	−0·67	7·69
	26–30	+0·41	+0·18	+1·24	+0·16	+1·11	−0·41	+0·33	−0·08	+0·28	−1·49	−0·10	−0·48	−0·70	+0·28	−0·66	7·44
Oct.	1– 5	+0·45	+0·02	+1·27	+0·29	+1·29	−0·45	+0·31	−0·18	+0·50	−1·51	−0·04	−0·78	−0·71	+0·31	−0·70	7·17
	6–10	+0·63	−0·01	+1·14	+0·67	+1·41	−0·42	+0·22	−0·23	+0·49	−1·75	−0·03	−1·05	−0·50	+0·17	−0·70	6·91
	11–15	+0·82	+0·12	+1·15	+0·73	+1·46	−0·15	+0·14	−0·28	+0·46	−1·88	−0·29	−1·23	−0·40	+0·28	−0·90	6·60
	16–20	+0·78	+0·56	+1·18	+0·60	+1·48	−0·13	+0·18	−0·27	+0·52	−1·94	−0·55	−1·23	−0·45	+0·32	−1·10	6·27
	21–25	+0·86	+0·63	+1·20	+0·50	+1·40	−0·01	+0·41	−0·26	+0·65	−1·91	−0·78	−1·14	−0·67	+0·16	−1·11	5·91
	26–31	+0·94	+0·59	+1·12	+0·47	+1·21	+0·12	+0·58	−0·38	+0·60	−1·81	−0·92	−1·05	−0·73	+0·35	−1·09	5·54
Nov.	1– 5	+0·74	+0·58	+0·89	+0·51	+1·11	+0·20	+0·76	−0·43	+0·46	−1·72	−0·96	−0·91	−0·68	+0·46	−1·08	5·19
	6–10	+0·51	+0·79	+0·72	+0·43	+0·98	+0·33	+0·76	−0·44	+0·46	−1·63	−0·89	−0·80	−0·58	+0·35	−0·92	4·85
	11–15	+0·40	+0·85	+0·69	+0·36	+0·89	+0·39	+0·67	−0·47	+0·43	−1·50	−0·85	−0·75	−0·58	+0·25	−0·78	4·59
	16–20	+0·37	+0·79	+0·63	+0·34	+0·84	+0·40	+0·92	−0·44	+0·45	−1·42	−0·82	−0·74	−0·58	+0·05	−0·72	4·38
	21–25	+0·26	+0·65	+0·55	+0·31	+0·82	+0·45	+1·53	−0·47	+0·35	−1·36	−0·79	−0·74	−0·66	−0·09	−0·74	4·23
	26–30	+0·19	+0·46	+0·49	+0·24	+0·76	+0·49	+1·72	−0·44	+0·38	−1·32	−0·75	−0·76	−0·68	−0·17	−0·66	4·08
Dec.	1– 5	+0·17	+0·17	+0·53	+0·18	+0·76	+0·58	+1·61	−0·36	+0·40	−1·28	−0·72	−0·76	−0·59	−0·17	−0·59	3·92
	6–10	+0·21	+0·19	+0·50	+0·18	+0·77	+0·67	+1·53	−0·36	+0·44	−1·28	−0·67	−0·74	−0·57	−0·24	−0·59	3·80
	11–15	+0·24	+0·24	+0·55	+0·15	+0·77	+0·72	+1·30	−0·33	+0·50	−1·31	−0·68	−0·69	−0·56	−0·25	−0·63	3·70
	16–20	+0·21	+0·21	+0·54	+0·15	+0·85	+0·73	+1·13	−0·26	+0·46	−1·32	−0·62	−0·63	−0·55	−0·23	−0·61	3·58
	21–25	+0·15	+0·15	+0·62	+0·18	+0·87	+0·70	+1·01	−0·25	+0·42	−1·36	−0·58	−0·60	−0·53	−0·21	−0·58	3·46
	26–31	+0·15	+0·15	+0·67	+0·18	+0·83	+0·67	+0·94	−0·22	+0·38	−1·37	−0·54	−0·59	−0·53	−0·22	−0·54	3·35
Yearly	**Mean***	−0·12	+0·07	+0·16	+0·45	+0·54	+0·77	+0·60	+0·21	+0·04	−0·40	−0·62	−0·44	−0·70	−0·28	−0·33	3·77
	Max.†	+0·76	−0·14	+0·84	−0·30	+0·76	+0·68	+0·56	−0·20	+0·52	−1·28	−0·14	−0·12	−1·05	0·00	−0·84	8·20
	Min.‡	−0·68	−0·17	−0·47	+0·22	+0·22	+0·98	+0·52	+0·56	−0·21	+0·16	−0·41	−0·26	−0·17	−0·35	+0·05	1·30

* Mean derived from daily readings. † Highest reading recorded in year. ‡ Lowest reading recorded in year.

At a short distance, 5 kilometres, above Aswan Cataract the Nile bends sharply to the east for a few hundred metres and then resumes its northerly course, thus forming under its left bank a back-water which in flood becomes a powerful eddy which has scoured a deep hole. This has given rise to a local legend that from this point an underground branch of the Nile flows to the oases of Kharga and Dakhla to supply their deep-seated wells, but the nearest of these is situated at a distance of 230 kilometres from this point and obtain their supply of water from the summer rains which fall on the northern half of Kordofan and percolate rapidly into the sandstone strata which here cover the granite of the old land surface and in their turn pass beneath the limestone beds which form the walls of the oases.[1]

From June to September 1893, the volumes discharged by the Nile were measured at Demhid, Dosha and Gertasse under the direction of Sir William Willcocks and from these the discharge table for Aswan[2] was computed.

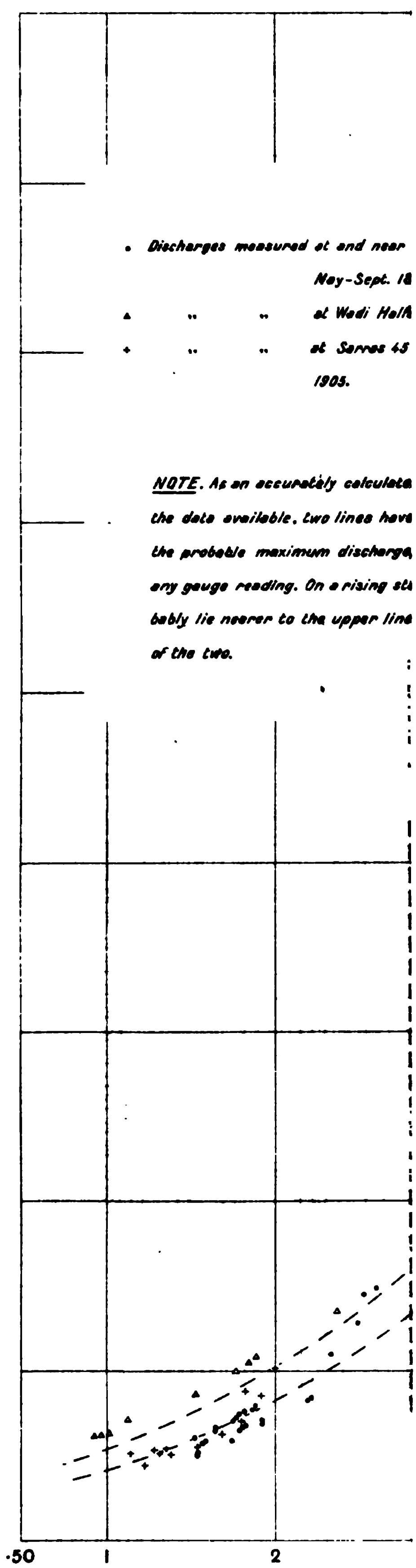
The results are given in the following table for comparison with those given above for Khartoum (p. 228). Berber (p. 279) and Sarras (p. 280).

VOLUME DISCHARGED BY THE NILE ABOVE ASWAN.

Date		Mean Width	Mean Depth	Sectional area	Mean Velocity	Discharge
		m.	m.	m^2	m. p. s.	$m.^3$ p. s.
1893						
May	21..	522	2·00	1036	0·668	693
„	22..	522	1·96	1023	0·656	672
„	25..	520	1·90	992	0·668	663
„	26..	520	1·90	992	0·661	657
„	27..	521	1·90	992	0·642	638
„	30..	520	1·79	933	0·610	569
June	18..	425	2·45	1040	0·569	592
„	19..	425	2·48	1054	0·473	500
„	21..	426	2·50	1069	0·477	510
„	23..	427	2·56	1095	0·506	554
„	24..	429	2·59	1112	0·514	572
„	26..	430	2·60	1136	0·561	638
„	29..	430	2·64	1415	0·464	657
July	3..	432	2·86	1234	0·561	692
„	4..	434	2·85	1261	0·581	733
„	5..	435	2·97	1296	0·579	751
„	6..	438	3·05	1339	0·563	755
„	11..	465	2·93	1362	0·599	816
„	12..	465	2·99	1392	0·598	832
„	16..	409	4·30	1758	0·617	1085

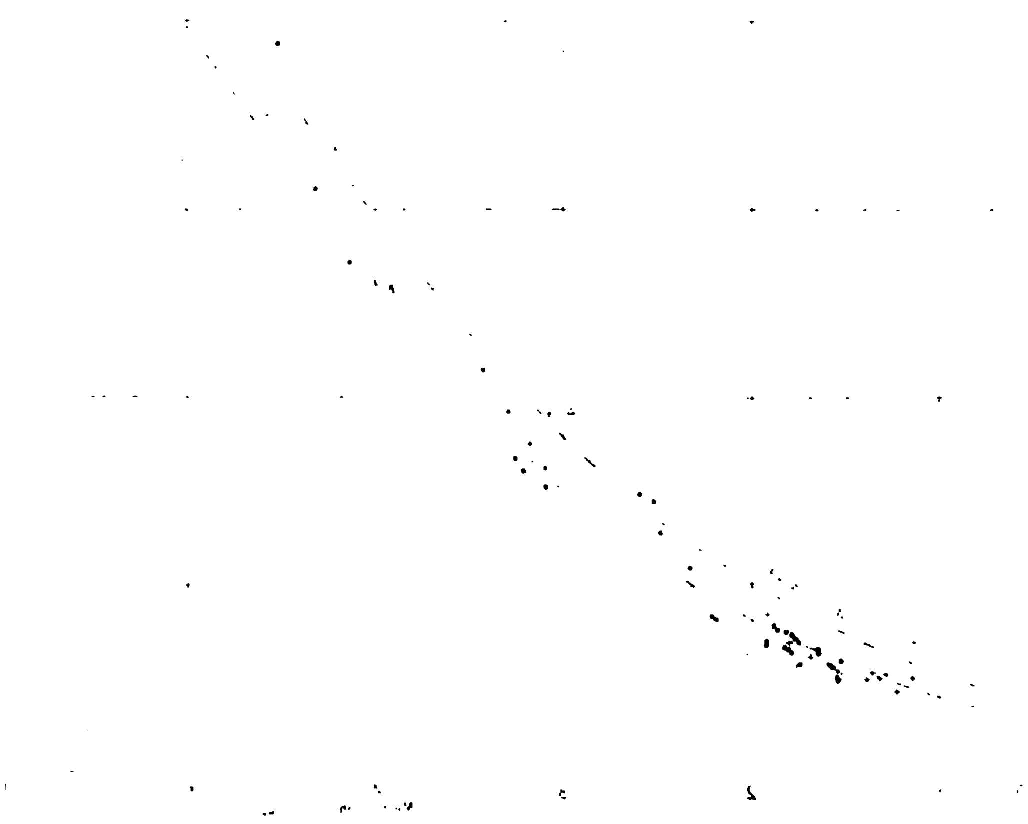
[1] cf. Rohlfs. "Wo von kommt das Wasser der Oasen." Zeitsch. f. Erdkunde, Berlin.
[2] Report on Perennial Irrigation. Cairo 1894. Appendix III.

Provisiona



Survey Department.

Provisional Discharge Curve for WADI HALFA



VOLUME DISCHARGED BY THE NILE ABOVE ASWAN—(*continued*).

Date		Mean Width	Mean Depth	Sectional area	Mean Velocity	Discharge
		m.	m.	m^2	m. p. s.	$m.^3$ p. s.
1893						
July	17..	409	4·54	1857	0·683	1269
„	18..	410	4·79	1963	0·730	1434
„	19..	411	5·06	2078	0·706	1467
„	20..	412	5·17	2124	0·764	1625
„	21..	412	5·32	2185	0·695	1520
„	22..	413	5·34	2202	0·722	1591
„	23..	413	5·37	2221	0·749	1666
„	24..	413	5·60	2313	0·827	1914
„	25..	416	5·87	2446	0·871	2131
„	26..	418	6·23	2604	0·991	2581
„	27..	419	6·60	2764	0·960	2706
„	28..	421	6·82	2869	1·080	3099
„	29..	424	7·43	3144	1·230	3867
„	30..	429	8·23	3528	1·365	4816
„	31..	429	8·55	3671	1·467	5386
Aug.	1..	430	8·63	3712	1·495	5552
„	2..	431	8·88	3830	1·428	5475
„	3..	433	8·94	3871	1·444	5589
„	4..	435	9·26	4020	1·492	6023
„	7..	437	9·66	4220	1·624	6857
„	8..	438	10·00	4384	1·727	7571
„	9..	439	10·10	4430	1·721	7625
„	10..	439	10·10	4439	1·797	7981
„	11..	439	10·05	4412	1·748	7714
„	12..	439	10·00	4382	1·681	7368
„	13..	439	9·95	4365	1·646	7087
„	14..	439	9·98	4386	1·638	7186
„	15..	441	10·05	4466	1·736	7755
„	16..	441	10·34	4558	1·724	7861
„	17..	441	10·45	4622	1·795	8298
„	18..	442	10·55	4654	1·738	8090
„	19..	443	10·60	4693	1·765	8287
„	20..	443	10·55	4664	1·794	8368
„	21..	443	10·62	4705	1·808	8719
„	22..	444	10·85	4815	1·818	8757
„	23..	444	10·85	4811	1·828	8799
„	24..	443	10·75	4756	1·710	8087
„	25..	444	10·75	4756	1·763	8389
„	26..	444	10·55	4695	1·760	8281
„	27..	443	10·73	4753	1·932	9086
„	28..	444	10·68	4740	1·935	9171
„	29..	443	10·60	4694	1·905	8947
„	30..	443	10·55	4687	1·805	8460
„	31..	443	10·53	4672	1·817	8490
Sept.	1..	443	10·52	4656	1·836	8553
„	2..	442	10·48	4632	1·873	8679
„	3..	442	10·41	4599	1·759	8094
„	4..	442	10·36	4574	1·696	7757
„	5..	442	10·31	4556	1·719	7833
„	6..	442	10·34	4570	1·662	7599
„	7..	442	10·33	4565	1·663	7596
„	8..	442	10·48	4626	1·686	7803
„	9..	442	10·50	4643	1·690	7849

VOLUME DISCHARGED BY THE NILE ABOVE ASWAN—(*continued*).

Date	Mean Width	Mean Depth	Sectional area	Mean velocity	Discharge
	m.	m.	m^2	m. p. s.	m^3 p. s.
1893					
Sept. 10..	442	10·55	4685	1·702	7976
" 11..	442	10·60	4697	1·632	7669
" 12..	443	10·70	4748	1·734	8235
" 13..	443	10·90	4811	1·715	8254
" 14..	444	10·90	4824	1·778	8580
" 15..	444	10·71	4748	1·696	8051
" 16..	443	10·62	4699	1·635	7686
" 17..	442	10·55	4672	1·659	7752
" 18..	442	10·50	4646	1·653	7680
" 19..	442	10·50	4646	1·682	7816
" 20..	442	10·58	4682	1·694	7933
" 21..	443	10·75	4760	1·733	8254
" 22..	443	10·85	4803	1·736	8239
" 23..	443	10·79	4782	1·699	8127

The position of the lines of section were :

DATE	PLACE	KILOMETRES FROM	
		Wadi-Halfa	Aswan
May 21-30	Dehmid	326	19
June 18-26 .. .. .. July 3 -12	Gertasse	301	44
June 29 .. .. .. July 16-Sept 23.. ..	Dosha	327	18

and these sites are within the area which is now annually flooded by the reservoir.

A few discharges have been measured at Wadi Halfa which are given in the following table :—

Date	Halfa Gauge	Discharge Cubic metres per second	Date	Halfa Gauge	Discharge Cubic metres per second
	metres			metres	
1901			1902		
December 5	3·08	1907	April 12	1·34	533
1902			" 17	1·30	507
January 23	2·00	1012	" 26	1·22	434
" 30	1·93	835	May 31	1·14	507
February 5	1·88	777	June 23	1·68	841
" 13	1·76	710	July 1	1·82	867
" 20	1·68	609	" 14	2·52	1,287
" 27	1·60	632	" 24	3·18	1,750
March 16	1·38	489	August 5	3·90	3,000
April 6	1·28	526	" 26	5·91	5,879

The discharge table which has hitherto been used in connection

with the Aswan gauge is no longer applicable in consequence of the dam having been built upstream of it; the Wadi Halfa gauge is now the one furthest downstream which records the normal variation of the river level unaffected by artificial works. Pending the completion of a full set of measurements at Sarras an attempt has been made[1] to compile a provisional discharge-table for the Wadi-Halfa gauge from the data obtained at Sarras, up to August 20, 1905, Wadi-Halfa and upstream of Aswan, and the result is given on Plate XXXVII. Unfortunately all the measurements which are available have been taken when the river has been rising, so that they are only approximately applicable to the gauge readings of a falling flood; moreover the data of 1893 are derived from sites at a considerable distance from Wadi Halfa, so that the discharge curve must be considered as an approximation until fuller data from Sarras are available.[2]

The Aswan gauge was established by Mahmud Pasha el Falaki in 1869, on the island of Elephantine, in the same covered stairway as the ancient Egyptian nilometer but on the other wall face. For this daily readings are available from June 19, 1869, to the present date, except during an interval from November 13, 1869, to March, 1, 1870, during which no readings were recorded; the scale is in piks and qirats; 1 pik = 24 qirats = 0·540 metre.

At Aswan, for the series of years 1870-1902, the mean date for the lowest reading was June 1, the earliest being May 5, 1887, and the latest June 22, 1882, while the average deviation from the date was ten days. Here the mean date for the highest stage, as deduced from the thirty-four years 1869-1902, is September 4, the earliest date being August 19, and the latest being October 1, while the mean deviation from September 4 is eight days.

Year	Minimum			Maximum		
	Date	After April 30	Difference from mean date.	Date	After August 1	Difference from mean date.
1869		Doubtful		Sept. 4 ..	20	0
1870	June 14 ..	45	+13	„ 7 ..	23	+ 3
1871	„ 16 ..	47	+15	Aug. 18 ..	3	−17
1872	May 25 ..	25	− 6	Sept. 18 ..	34	+14
1873	June 3 ..	34	+ 2	„ 1 ..	17	− 3
1874	May 28 ..	28	− 4	„ 6 ..	22	+ 2

[1] By Mr. J. I. Craig.

[2] A rigorous discussion of the volume most probably discharged by the river in this reach is in hand in the computing office of the Survey Department. The values derived from the data given above, and from the volume discharged through the sluices of the Aswan dam are not wholly in agreement, and the difference is apparently due to loss by seepage where the river flows over the sandstone.

Year	Minimum			Maximum		
	Date	After April 30	Difference from mean date.	Date	After August 15	Difference from mean date.
1875	May 23 ..	23	− 9	Sept. 11 ..	27	+ 7
1876	June 11 ..	42	+10	" 7 ..	23	+ 3
1877	May 26 ..	26	− 6	Aug. 20 ..	5	−15
1878	June 8 ..	39	+ 7	Oct. 1 ..	46	+26
1879	May 23 ..	23	− 9	Sept. 13 ..	29	+ 9
1880	June 3 ..	34	+ 2	" 2 ..	18	− 2
1881	May 14 ..	14	−18	" 4 ..	20	0
1882	June 22 ..	53	+21	Aug. 28 ..	13	− 7
1883	May 27 ..	27	− 5	Sept. 17 ..	33	+13
1884	" 25 ..	25	− 7	" 1 ..	17	− 3
1885	June 20 ..	51	+19	Aug. 28 ..	13	− 7
1886	" 3 ..	34	+ 2	Sept. 22 ..	38	+18
1887	May 5 ..	5	−27	" 1 ..	17	− 3
1888	June 4 ..	35	+ 3	Aug. 24 ..	9	−11
1889	" 4 ..	35	+ 3	Sept. 1 ..	17	− 3
1890	May 28 ..	28	− 4	" 2 ..	18	− 2
1891	" 17 ..	17	−15	" 7 ..	23	+ 3
1892	June 5 ..	36	+ 4	" 20 ..	36	+16
1893	" 18 ..	49	+17	" 14 ..	30	+10
1894	May 8 ..	8	−14	Aug. 25 ..	10	−10
1895	June 21 ..	52	+20	" 22 ..	7	−13
1896	" 11 ..	42	+10	Sept. 2 ..	18	− 2
1897	May 27 ..	27	− 5	" 1 ..	17	− 3
1898	June 21 ..	52	+20	Aug. 28 ..	13	− 7
1899	" 1 ..	32	+ 0	Sept. 4 .	20	0
1900	May 26 ..	26	− 5	Aug. 19 ..	4	−16
1901	" 10 ..	10	−22	Sept. 6 ..	22	+ 2
1902	June 6 ..	37	+ 5	" 17 .	33	+13
Mean	June 1 ..	—	±10	Sept. 4 ..	—	±8

In the following table is given the volume discharged in each year from 1869 to 1903 from July 1 to October 31, which has been computed from the discharge table given by Sir W. Willcocks.[1] The ratio between floods of different magnitude bears out what has been deduced from two years' discharges at Khartoum, namely, that an abnormally low Nile is about two-thirds of the volume of anormal flood, while a maximum flood is nearly the double of an abnormally low flood. These proportions should be approximately reproduced in the Abyssinian rainfall of these years, but observations there are as yet too few to show this elearly.

[1] Perennial Irrigation, Cairo 1894, App. III., Table I.

VOLUME OF FLOOD AT ASWAN, JULY 1 TO OCTOBER 31, IN MILLIONS OF CUBIC METRES.

Year	Ratio to mean flood	Volume	Variation from mean	Mean of five years.	Variation from five-year mean.
1869	1·18	77,133·6	+11,965·4	..	..
1870	1·23	80,183·5	+14,995·3	..	..
1871	1·05	68,371·8	+ 3,183·6	70,551·7	+ 5,249·1
1872	1·11	72,065·4	+ 6,877·2	71,669·5	+ 6,366·9
1873	0·84	55,004·4	−10,183·8	69,992·2	+ 4,689 6
1874	1·26	82,622·6	+17,434·4	70,493·5	+ 5,190·9
1875	1·10	71,896·9	+ 6,708·7	65,197·3	− 105·3
1876	1·09	70,878·2	+ 5,690·0	70,312·8	+ 5,010·2
1877	0·70	45,584·2	−19,604·0	68,625·9	+ 3,323·3
1878	1·24	80,582·3	+15,394·1	67,089·7	+ 1,787·1
1879	1·14	74,187·8	+ 8,999·6	65,047·9	− 254·7
1880	0·98	64,215·9	− 972·3	66,857·8	+ 1,555·2
1881	0·93	60,669·2	− 4,519·0	64,302·7	− 999·9
1882	0·84	54,633·7	−10,554·5	60,350·5	− 4,952·1
1883	1·04	67,806·7	+ 2,618·5	60,439·0	− 4,863·6
1884	0·83	54,427·2	−10,761·0	60,171·9	− 5,130·7
1885	0·99	64,658·3	− 529·9	64,769·1	− 533·5
1886	0·91	59,333·5	− 5,854·7	60,568·0	− 4,734·6
1887	1·19	77,619·6	+12,431·4	62,659·8	− 2,642·8
1888	0·72	46,801·6	−18,386·6	64,363·7	− 938·9
1889	1·00	64,886·0	− 302·2	65,606·0	+ 303·4
1890	1·12	73,177·8	+ 7,989·6	65,738·0	+ 435·4
1891	1·01	65,544·8	+ 356·6	69,274·8	+ 3,972·2
1892	1·20	78,279·7	+13,091·5	72,190·1	+ 6,887·5
1893	0 99	64,485·9	− 702·3	72,556·6	+ 7,254·0
1894	1·22	79,462·5	+14,274·3	73,338·6	+ 8,036·0
1895	1·15	75,009·9	+ 9,821·7	69,259·8	+ 3,957·2
1896	1·06	69,455·2	+ 4,267·0	70,257·4	+ 4,954·8
1897	0·89	57,885·4	− 7,302·8	62,565·1	− 2,737·5
1898	1·07	69,473·8	+ 4,285·6	59,180·8	− 6,121·8
1899	0·63	41,001·1	−24,187·1	56,595·1	− 8,707·5
1900	0·89	58,088·4	− 7,099·8	53,306·5	−11,996·1
1901	0·87	56,526·8	− 8,661·4	51,049·9	−14,252·7
1902	0·63	41,442·6	−23,745·6	..	..
1903	0·89	58,190·4	− 6,997·8	..	..
	Mean	65,188·2	Mean	65,302·6	

It will be noticed that the mean volume discharged is 65,188 million cubic metres, which is not much greater than that obtained from the Khartoum observations for 1903, a year somewhat below the normal, although the Aswan volume includes the discharge of the Atbara, and also that which the White Nile was contributing, a quantity which in July and October is not inconsiderable, though small in August and September. These Aswan values would appear, therefore, to be rather below the truth. In the memoir where the discharge table is published,

no details are given of the observations from which the table was computed. The greater discharge when the river is rising than when it is falling, for the same gauge-reading, is mentioned, but it is not stated how this was dealt with in preparing the table. However, though the totals may be rather low, their ratios to one another should not be appreciably altered.

In 1904, the volume of the flood calculated in the same way was 47,020·8 millions of cubic metres, being 0·75 of a mean flood, while that of 1905 was only 42,000·0 millions or 0·65 of a mean flood.

Summary.—From Khartoum and Berber to Aswan the waters of the White Nile, the Blue Nile and the Atbara flow in a single stream to Egypt. From a comparison of these three tributaries we have seen that each plays a somewhat different part in the regimen of the river. The relations are simplest in April just before the Blue Nile begins to rise for then the Atbara supplies nothing, the Blue Nile but little, while the White Nile supplies by far the greater share of the Nile. As the Abyssinian rains increase the contributions of the Blue Nile and Atbara become important, and soon the White Nile does little more than fill its valley as the water level of the Blue Nile continues to rise. When the latter falls in September and in October, the White Nile discharge increases, and is at its maximum in December, but decreases rapidly after January when the Sobat has fallen considerably.

The Nile in this reach is eroding its bed throughout and with considerable rapidity in certain of the cataracts where a narrow channel and a steep slope occur. Thus it is forming no flood plains and cultivation only reaches any considerable development where the valley is wider for a sufficient distance to render a canal practicable. Evaporation is at a maximum in the northern part, where rain is almost unknown and is certainly wholly ineffective since only an occasional storm passes to the north of Dongola. The Nile supply in this reach therefore has reached its maximum and from Berber northwards steadily diminishes by evaporation, seepage, and by the utilization of its waters for irrigation.

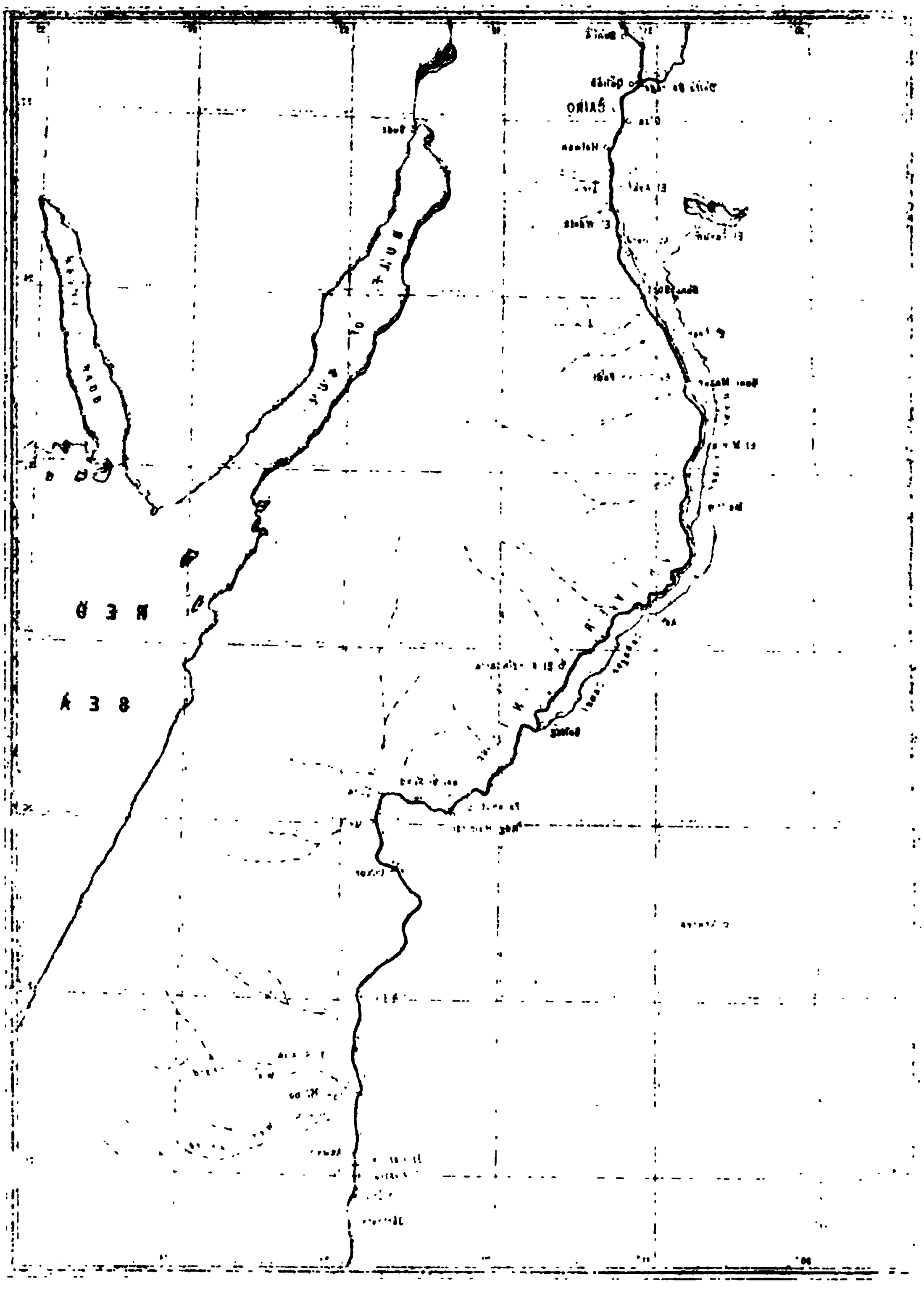
CHAPTER VIII.

The Nile Valley from Aswan to Cairo.

North of Aswan the Nile flows through a fertile and highly cultivated valley which opens out into the Delta 25 kilometres north of Cairo, and in this part of its basin the river occupies the western margin, all drainage lines of any importance coming in from the east on the right bank. This is due to the very unequal relief of the country lying on either side of the river. On the east the divide between the Nile and the Red Sea is formed by a range of ancient crystalline rocks running parallel to the coast at a short distance from it, and which rises to a considerable height since many of its peaks reach 1200 metres while some few attain or even exceed 2000 metres. From the foot of this range the plateau, formed of cretaceous and tertiary sandstones and limestone, slopes gradually westwards towards the valley of the Nile but even here the edge of the plateau rises to 200 and 250 metres above the valley floor in many places. On the west of the valley conditions are very different; the desert plateau rises rapidly from the valley, often as steep cliffs, and more gradually for some 10-20 kilometres beyond this. To this succeeds an almost horizontal plateau without any well defined drainage lines, rising here and there to low flat-topped ridges, but on the whole falling very gently to the westward, Thus there is no catchment basin of any extent on the west of the Nile, and the feebly marked drainage lines extend but a few kilometres back on to the plateau; only such rainstorms as fall near the plateau edge are drained towards the river and but rarely does the water reach the margin of the cultivation. What falls on the plateau drains into shallow wind-worn depressions and there soaks into the rock or is soon evaporated. The area of the basin west of the Nile may in this part of its course be limited to the 5 to 10 kilometres beyond the limits of the cultivation, and of this area none of it can be said to be effective seeing how small a quantity of rain falls. A few rainstorms occur every winter but they are usually very local in their effect. On the eastern side the much larger area, and the steeper slopes, together with a greater frequency of rain near the Red Sea hills make the winter rainfall a more important factor; in about every second year one or other of the larger wadies comes down in flood, sometimes so suddenly as to carry away camels and sheep which may be grazing

PLATE XXXVIII

THE BASIN OF THE NILE, ASWAN – CAIRO



which the river flows to-day ; so that under the present conditions the solid geology of this part has but little effect on the physical conditions of the river. The almost horizontally bedded strata of sandstone and clay in the southern area and of limestone in the northern part dip very gently in a northerly direction but it is only at a few points that the river washes them; for the most part it is confined within the limits of the alluvial plain.

Every few years slight earthquake tremors show that movement along the lines of facture has not wholly ceased and though these of recent years March 28, 1846, October 12, 1856 and June 24, 1870 for instance, have been on the whole slight, in 1303 a very violent shock occurred on August 8 by which much damage and serious loss of life was caused.[1]

Climate.—At Aswan two series of observations exist which agree very fairly well. The first was taken at the Military Hospital at the north end of the town, while for the second series the thermometer screen is on the east bank of the river just below the reservoir dam and about 200 metres from the river.

For Luxor the winter observations of Dr. Leigh Canney have been utilised.

At Assiut a climatological station was established in 1900 but at first the observations were not quite regularly made, only one daily observation being taken in the summer months of 1901.

At Sheikh Fadl and Nag Hamadi the thermometers are exposed over cultivated land in screens and the results should represent the temperature conditions well.

The Beni Suef observations extend over a longer period, 1893-1904 and give mean values which must be very near the truth. The instruments have been exposed under a verandah so that the winter minima are not as low as they should be.

At Giza (Survey Department offices) observations have been made from 1902; the station is situated in cultivated lands, and is about 300 metres from the Nile ; the observations are reliable, but the series is too short a one to give the correct means especially for the winter months.

For Cairo the observations of the Abbassia Observatory (1869-1903) have been utilized and these give reliable mean values. Its position on the edge of the cultivated lands of the Delta with the desert to the east and south probably has affected the results slightly, giving

[1] De Montessus in "Beiträge zur Geophysik" vol. IV, gives for Egypt and Ethiopia 12 epicentres and 59 earthquakes as traceable from the works of travellers and historians.

higher temperatures in the months when easterly winds prevail, and lower ones during westerly winds than would have been recorded at stations wholly in the cultivation or in the desert respectively.

Mean monthly temperature.

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
Cairo[1]	**12·3**	13·8	16·9	21·2	24·8	27·7	**28·6**	28·1	25·6	23·6	18·9	14·8	21·4
Giza	**10·9**	13·0	15·2	19·3	22·7	24·8	25·7	**26·1**	24·0	22·0	17·1	12·9	19·4
Beni-Suef ..	**12·6**	14·1	16·8	20·8	24·9	26·9	**28·1**	27·2	25·3	23·2	18·5	15·0	21·1
Sheikh Fadl.	**11·0**	14·0	17·0	21·3	25·2	27·4	**28·6**	28·5	25·5	22·8	16·7	12·7	20·9
Assiut . ..	**10·6**	13·5	16·9	21·9	25·8	28·7	**29·9**	29·5	26·6	23·6	17·3	13·8	21·5
Nag Hamadi	**12·4**	15·7	19·4	24·7	27·3	29·9	**30·1**	**30·1**	27·6	25·0	23·5	14·8	23·3
Luxor . ..	15·4	17·4	21·1	24·1	..	..	..	..	..	..	..	16·9	..
Kharga. ..	15·8	**15·3**	18·7	23·9	29·4	31·6	31·3	**32·3**	27·1	24·0	18·1	..	[26·1]
Aswan Rest Camp.	16·8	17·5	20·9	26·6	30·3	33·3	33·9	32·0	30·4	28·6	23·6	18·2	26·0
Aswan Reservoir.	**14·5**	18·5	21·4	26·1	30·0	32·4	**32·7**	32·4	30·3	27·9	21·7	17·0	25·3

Mean maximum temperature.

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
Cairo[1]	18·2	21·1	24·2	28·6	32·6	35·1	**36·1**	34·9	32·2	30·1	24·3	20·2	28·2
Giza	**19·1**	22·2	24·5	28·8	32·2	34·2	**34·9**	**34·9**	32·5	30·7	25·6	21·3	25·5
Beni Suef ..	**19·5**	20·9	24·2	28·3	32·5	34·3	**34·9**	33·4	30·8	29·1	24·8	21·5	27·8
Assiut	**20·2**	24·7	28·4	32·5	36·6	37·7	**37·9**	37·8	34·0	31·3	27·7	22·5	27·6
Sheikh Fadl	**19·0**	22·8	25·7	29·9	33·7	35·3	**36·2**	35·9	32·1	28·8	24·4	21·0	28·7
Nag Hamadi	**20·5**	25·3	28·8	**34·0**	37·1	**39·2**	38·9	38·6	35·2	33·3	27·3	23·5	31·7
Luxor . ..	23·1	25·5	29·4	32·1	..	..	..	..	..	..	31·1	24·3	..
Aswan Rest Camp.	23·8	24·2	28·9	33·6	39·3	**42·3**	**42·3**	39·2	37·6	35·8	29·6	24·9	34·9
Aswan Reservoir.	**22·9**	28·0	31·1	36·2	39·1	41·4	41·5	**41·9**	39·7	38·8	31·7	27·3	34·9

Mean minimum temperature.

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
Cairo[1]	6·9	8·2	9·9	12·8	15·9	18·5	**20·8**	**20·8**	18·9	17·1	12·3	8·8	14·4
Giza .. .	**6·3**	7·2	9·0	11·9	14·6	17·4	19·0	**20·1**	18·2	16·5	11·9	8·2	13·4
Beni-Suef ..	**5·8**	7·2	9·5	13·2	17·3	19·6	**21·3**	21·0	19·7	17·3	12·2	8·5	14·4
Assiut . ..	**4·7**	6·7	9·4	14·0	18·5	21·2	22·6	**22·9**	20·7	17·4	10·9	7·0	14·7
Sheikh Fadl	**3·1**	5·3	8·4	12·8	16·8	19·5	21·0	**21·2**	18·9	16·7	9·0	4·4	13·1
Nag Hamadi	**4·2**	6·2	[9·8]	[15·3]	17·5	20·5	21·0	**21·4**	20·0	16·7	9·8	6·0	14·0
Luxor . ..	7·6	9·3	12·7	16·1	..	..	..	..	..	..	12·9	9·6	..
Aswan Rest Camp.	9·9	10·7	12·9	18·7	21·3	24·3	**25·5**	24·8	23·3	21·2	17·5	11·5	18·5
Aswan Reservoir.	**9·0**	11·5	13·8	18·3	22·0	24·2	24·7	**25·0**	23·0	20·7	15·3	11·4	18·2

[1] Abbassia observatory.

Range (maximum—minimum)

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
Cairo	11·4	12·2	14·3	15·8	**16·7**	16 6	15·3	14·1	13·3	13·0	12·0	11·4	13·8
Giza	12·8	15·0	15·5	16·9	**17·6**	16·8	15·9	14·8	14·3	14·2	13·7	13·1	15·0
Beni-Suef ..	13·7	13·7	14·7	15·1	**15·2**	14·7	13·6	12·4	11·1	11·8	12·6	13·0	13·5
Assiut.. ..	15·5	18·0	**19 0**	18·5	18·1	16·5	15·3	14·9	13·3	13·9	16·8	15·5	16·3
Sheikh Fadl.	16·1	**17·5**	17·3	17·1	16·9	15·8	15·2	14·7	13·3	12·1	15·4	16·6	15·7
Nag Hamadi	16·3	19·1	19·0	18·7	19·6	**19·7**	17·9	17·2	15·2	16·6	17·5	17·5	17·8
Luxor.. ..	15·5	16·3	16·7	16·1	..	..	..	..	..	..	18·2	14·7	..
Aswan Rest Camp.	13·9	13·5	14·0	14·9	**18·0**	**18·0**	16·8	14·4	14·3	14·6	12·1	13·4	14·8
Aswan Reservoir .	13·9	16·5	17·3	17·9	17·1	17·2	16·8	16·9	16·7	18·1	16·4	15·9	16·7

Mean monthly minimum extremes

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Cairo	2·5	4·0	5·6	8·8	11·7	16·0	**18·3**	18·2	15·8	13·6	8·5	4·5
Giza	**2·3**	3·5	5·2	7·6	10·7	14·8	16·5	**17·5**	14·8	12·5	8·0	3·9
Beni-Suef	**1·9**	3·6	5·4	8·8	12·7	16·4	**19·0**	18·4	16·8	14·0	8·3	4·0
Assiut	**0·5**	2·0	4·9	9·0	13·6	17·6	18·8	**20·5**	17·8	12·9	6·3	2·5
Sheikh Fadl ..	–1·9	0·8	2·9	7·0	11·2	15·8	17·7	**18·4**	15·5	10·8	4·2	0·1
Nag Hamadi ..	**0 9**	2·0	5·5	9·5	12·0	16·9	**18·6**	18·0	15·6	11·9	5·3	2·3
Aswan Rest Camp	6·1	5·3	8·3	14·1	16·9	20·2	22·2	22·5	20·6	17·3	12·2	6·9
Aswan Reservoir.	**4·9**	7·3	9·2	13·9	17·6	20 5	**21·9**	21·5	19·1	16·4	8·8	4·3

Mean monthly maximum extremes.

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Cairo	**22·6**	28·2	33·8	37·6	40·4	**41·6**	39·7	40·0	36·9	35·2	29·1	25·3
Giza	**23·6**	28·3	31·6	**40·4**	40·3	39·8	39·0	38·4	36·8	37·6	33·5	25·4
Beni-Suef	**24·9**	27·8	32·7	37·0	39·8	**40·2**	38·6	37·8	35·3	33·1	29·2	26·4
Assiut..	**25·4**	30·8	37·5	42·4	**44·0**	43·9	42·3	41·2	38·8	37·1	32·1	27·8
Sheikh Fadl ..	23·6	28·6	34·6	40·1	42·2	41·4	40·2	39·3	37·8	32·8	30·0	27·2
Nag Hamadi ..	25·4	30·8	37·1	41·9	42·5	**44·5**	43·4	43·0	39·9	38·4	34·5	28·7
Aswan Rest Camp	31·1	30·9	38·6	40·6	45·3	45·9	45·9	43·3	41·1	14·1	34·4	31·3
Aswan Reservoir.	29·2	33·9	39·7	44·9	45·1	44·6	**45·2**	44·3	42·2	41·5	38·2	32·8

Mean Relative Humidity

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
Cairo	69	65	59	51	47	47	50	56	62	66	66	70	51
Giza	82	77	70	63	57	57	63	67	73	75	75	81	70
Assiut ...	69	67	56	40	30	31	36	42	56	62	69	69	52
Aswan ...	51	37	32	30	25	24	22	23	30	39	34	51	33

Relative Humidity (8 or 9 a.m.)

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
Giza	87	84	74	68	65	64	73	76	80	80	77	86	76
Assiut ..	76	68	59	45	36	40	45	48	60	67	72	74	58
Kharga [1] ..	59	32	24	19	14	18	19	18	27	28	36	63	29
Aswan ..	58	48	38	34	29	28	27	28	37	42	47	54	39

Relative Humidity (2 or 3 p.m.)

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
Cairo	47	40	34	27	24	25	27	32	39	42	45	49	36
Giza	51	42	39	36	30	33	36	36	44	52	44	50	41
Assiut ..	34	44	24	21	16	17	22	22	31	38	48	46	30
Aswan ..	30	22	17	17	15	15	13	13	18	22	25	30	20

Mean Vapour Tension

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
Cairo	7·2	7·3	7·8	8·7	9·9	11·9	13·6	14·6	14·2	13·2	10·6	8·1	10·6
Giza	7·2	7·4	8·4	10·2	11·6	13·4	15·1	15·8	15·6	14·3	10·8	8·3	11·6
Assiut ..	6·4	7·2	6·8	7·2	8·4	10·1	10·4	11·3	12·8	13·0	10·0	7·7	9·3
Aswan ..	5·9	5·3	5·6	7·4	7·7	8·4	7·8	7·4	9·1	9·5	7·3	6·7	7·3

On leaving Aswan the river flows due north in a narrow valley hardly more than a kilometre wide and bounded by sandstone cliffs about 20-30 metres high ; behind this the desert rises slowly till on the west about 20 to 30 kilometres distant the steep face of the cretaceous

[1] Kharga Oasis gives desert values for comparison with those of the valley.

limestone cliffs is seen bounding the higher desert plateau (500 m.); on the east the rise is more gradual and here the Wadi Khareit with its tributary valleys drains the eastern plain for a distance of 200 kilometres finally meeting the Nile valley at Kom Ombo. Below this the valley widens somewhat and receives another main valley, Wadi Shaid, just above Silsila.

At Gebel Silsila the Nile flows through a comparatively narrow channel 350 metres wide and many writers have maintained that there was formerly a rocky barrier at this point which the river has in time removed.

At Edfu the river turns to the north-west and flows in an alluvial plain about 6 kilometres in width where high limestone cliffs bound the strip of land which has been depressed thus forming a convenient drainage line for the Nile. For many kilometres now the river occupies this trough in the limestone plateau following a direction which varies from north-west to a little east of north, except for some 60 kilometres below Qena where it turns abruptly somewhat south of west as far as Farshut. Beyond this the alluvial plain increases in width being 15 kilometres wide near Sohag, while near Mellawi it reaches 16, and at Beni Suef 21.

There is but little change in the geographical character of the valley until near Beni-Suef when the limestone plateau bends back so as to include the depression of the Fayum afterwards passing under later deposits and not again appearing on this side.

The general dimensions of the valley are shown in the following table and in the cross-sections on Plates XXXIX and XL.

Place.	Kilometres from Aswan.	Width.		Between cliffs.
		of River.	of alluvial plain.	
		metres	km.	km.
Aswan	0	800	..	2·8
Edfu	110	800	6·4	8
Luxor	219	1250	1·9	12·5
Quft	264	750	11·5	15
Farshut	355	1200	10·5	13
Sohag	448	450	15	18
Assiut	549	900	10	12
Mellawi	650	850	16	22
Minia	700	1000	11·5	17
Feshn	792	1000	13	17
Beni-Suef..	826	1500	21	24
El Ayat	895	800	7·5	9·5
Cairo	945	600	15	17

Taking the flood level of the river as giving approximately the slope of the flood plain we have.[1]

Place.	Distance.	Flood water-slope 1 in
	Kilometres.	
Aswan to Silsila..	70	11.500
Silsila to Qasr el Saad	250	14.800
Qasr el Saad to Khazindaria	150	12,300
Khazindaria to Assiut	60	11,800
Assiut to Beni Mazar	180	11,000
Beni Mazar to Ashment	90	11,000
Ashment to Cairo	100	11,600

The interesting depression of the Fayum which lies on the west of the Nile valley some 85 kilometres south of Cairo, no longer affects the regimen of the Nile but concerns rather the utilization of its water supply. In Pliocene times it was occupied by the sea which then extended for some distance up the Nile valley. Later on in Pleistocene times, when the drainage of North-Eastern Africa flowed down the Nile valley at a considerably higher level than to-day, the Fayum depression became a lake communicating with the river. Later on as the river eroded its bed, the depression was probably cut off from the valley, until in early historic times the river-bed had again risen sufficiently by deposition to render possible the diversion of part of its supply into the Fayum. From that time by regulating the amount so diverted it was possible to reclaim gradually almost the whole of the floor of this low-lying area for cultivation.[2] Now all that remains of the former lake is an area of 233 square kilometres of brackish water which is being reduced yearly as the water which reaches it is less than that which is removed by evaporation. The mean depth of the eastern portion is to-day 3·7 metres, while that of the western portion is 5·5 metres, the maximum depth being 8 metres.

Material carried in suspension by the Nile.—In this reach a large part of the material which has been scoured out of the ravines of the Abyssinian tableland by its torrents in the rainy season is deposited to form the flood plain which together with the Delta makes

[1] Willcocks. Egyptian Irrigation, 2nd Ed., London 1899. p.45.
[2] Cf. Beadnell, "The Topography and Geology of the Fayum Province," Cairo, 1905, p. 26.

up the land of Egypt, and it will be convenient to collect together the available data which bear upon the deposition of the Nile mud.

Since the White Nile plays but a very subordinate part in the flood and its velocity at this time is at the lowest, no suspended matter can then be furnished by it, but all must be derived from the Blue Nile and the Atbara. While the volume discharged by these rivers was being measured in 1902-3 some samples of silt were also collected, but being taken without specially designed apparatus they do not give an accurate representation of the silt in suspension since but a single sample was taken on each occasion from near the surface in the middle of the river and no attempt was made to determine the variation in the amount of silt in either a horizontal or a vertical direction, nor was the bottom-load ever determined.

Air dried only.

SEDIMENT IN SUSPENSION IN THE BLUE NILE OF KHARTOUM. *& surface*

Date.	Water taken litres.	Weight in grams.	Parts per million	Date.	Water taken litres.	Weight in grams	Parts per million
1902							
May 9	36	4.426	123	Nov. 13	15	1.220	81
„ 17	36	2.186	60	„ 20	15	0.970	65
„ 24	36	2.700	75	„ 27	15	1.070	71
„ 28	36	1.350	37	Dec. 4	15	0.620	41
June 2	36	1.750	49	„ 11	15	0.440	29
„ 14	36	4.150	115	„ 18	15	0.660	44
„ 21	18	6.150	342	„ 25	15	0.460	31
„ 28	18	5.350	297				
July 5	36	30.480	847	1903			
„ 17	36	13.590	377				
„ 24	36	13.625	378	Jan. 1	15	0.470	31
Aug. 2	36	37.650	1046	„ 8	15	0.400	27
„ 13	15	14.850	990	„ 15	15	0.420	28
„ 20	15	9.700	647	„ 22	15	0.350	23
„ 29	15	17.200	1147	„ 30	15	0.600	40
Sept. 4	15	23.600	1573	Feb. 5	15	0.650	43
„ 11	15	15.750	1050	„ 12	15	0.310	21
„ 18	15	9.320	621	„ 19	15	0.410	27
„ 25	15	6.590	439	„ 26	15	0.460	31
Oct. 2	15	6.140	409	Mar. 5	15	0.300	20
„ 9	15	3.600	240	„ 12	15	0.730	49
„ 16	15	2.590	173	„ 19	15	0.510	34
„ 23	15	2.250	150	„ 26	15	0.700	47
„ 30	15	1.810	121	April 2	15	0.600	40
Nov. 6	15	2.300	153	„ 9	15	0.750	50

These quantities of silt in suspension may be given also as the average for each month in 1902, a year of exceptionally low flood.

Month.	Average parts per millions	Month.	Average parts per million.
January	30	July	400
February	30	August	958
March	37	September	921
April	45	October	239
May	74	November	92
June	201	December	36

An observation made by Figari[1] at the junction of the Blue and White Niles north of Khartoum on July 30, 1837 gave 1000 parts per million which agrees fairly with those obtained in 1902.

Chélu[2] gives the amount of material in suspension in samples of Blue Nile water taken opposite the old Khartoum Arsenal on February 3 and August 15, 1877 as 1·5629 and 16·7341; the unit to which these figures refer is not mentioned but it may be grammes per 10 litres, which wonld be equivalent to 156 and 1673 parts per million. Neither size of the sample nor the method af collection is given.

The flood of 1902 was a very feeble one, being only 0·63 of a mean flood, so that the quantity of material in suspension is also below the average; Figari's result was taken about a month before the Blue Nile reached a maximum in a year of bad flood while Chélu's value of 1877 was in a year of bad flood and 14 days before the maximum level of the river though the last fact is not of so much weight since the highest velocity is usually a little before the highest gauge reading, when the river is still rising.

The Atbara has always been described as a river which carries a heavy load of sediment in flood and the only two measurements which have been made would seem to bear this out.

The single observation from the Atbara in flood in August 1902 giving 4758 parts per million of suspended matter is of interest, and should be verified by further investigation as it would appear as though this river discharging about one fifth of the volume of the Blue Nile

[1] Quoted by Ventre in "Sol Egyptien et Engrais." Bull, Inst. Egypt, N° 10, 1889, Cairo.
[2] " Le Nil, Le Soudan, l'Egypte," p. 25.

may at times carry material in suspension which in quantity may not be very greatly inferior to that of the Blue Nile.

Atbara.

Date.	Water taken, litres.	Weight in grams.	Parts per million.
1902			
August 24...	$9\frac{2}{3}$	46·0	4758
September 22...	15	8·5	567

Similar measurements of the silt carried in suspension by the water of the White Nile were also made during the same period, but as the point from which the water samples were taken was near the junction of the two streams, the results during the flood of the Blue Nile are unreliable as it is impossible to ensure that the silt was due to the White Nile water only; in fact the irregular increases shown are certainly due to silt from the water of the Blue Nile.

Date.	Water taken litres.	Weight in grams.	Parts per million.		Date.	Water taken litres.	Weight in grams.	Parts per million.
1902								
May 24.. ..	36	2.25	62		Nov. 20.. ..	15	2.54	169
„ 29.. ..	36	2.20	61		„ 27.. ..	15	1.20	80
June 3.. ..	18	3.00	167		Dec. 4.. ..	15	0.89	59
„ 14.. ..	36	4.85	135		„ 11.. ..	15	0.96	64
„ 21.. ..	36	3.65	101		„ 18.. ..	15	0.87	58
„ 28.. ..	36	2.50	69		„ 25.. ..	15	1.32	88
July 5.. ..	36	6.40	178					
„ 17.. ..	36	7.60	211		1903			
„ 24.. ..	36	5.75	160					
Aug. 2.. ..	36	9.90	275		Jan. 1.. ..	15	0.79	53
„ 13.. ..	15	4.66	311		„ 8.. ..	15	1.13	75
„ 20.. ..	15	1.37	91	Probably affected by water from the Blue Nile.	„ 15.. ..	15	1.21	81
„ 29.. ..	15	6.42	428		„ 22.. ..	15	2.11	141
Sept. 4.. ..	15	0.95	63		„ 30.. ..	15	0.95	63
„ 11.. ..	15	3.13	209		Feb. 5.. ..	15	1.01	67
„ 18.. ..	15	2.09	139		„ 12.. ..	15	0.95	63
„ 25.. ..	15	2.38	159		„ 19.. ..	15	0.83	55
Oct. 2.. ..	15	0.67	45		„ 26.. ..	15	0.73	49
„ 9.. ..	15	1.07	71		Mar. 5.. ..	15	0.61	41
„ 16.. ..	15	1.26	80		„ 12.. ..	15	1.05	70
„ 23.. ..	15	0.85	57		„ 19.. ..	15	0.84	56
„ 30.. ..	15	0.63	42		„ 26.. ..	15	0.55	37
Nov. 6.. ..	15	1.28	85		April 2.. ..	15	0.65	43
„ 13.. ..	15	1.31	87		„ 9.. ..	15	0.50	33

Neglecting the results obtained from July 5 up to September 25 as probably affected by the Blue Nile water the mean quantity of silt in the White Nile is 74 parts per million.

The samples from both the Blue and White Niles were taken approximately from the centre of the stream.

Until therefore more satisfactory data are available, which have been obtained carefully and which depend on a very large number of observations taken during the flood on frequent occasions and at numerous parts of the river section both vertically and horizontally, we must be content with a rough approximation to the true value. We may probably take 1400 parts per million as the maximum amount of suspended matter carried for 2 or 3 weeks by the Blue Nile in flood, but for the Atbara no estimate is at present possible. As all available data are derived from water samples collected at or close to the surface, a further addition, and probably a considerable one, has to be made for the large amount carried in the lower layers of the river and especially for that which is half carried half rolled along near the bottom. As no observations have yet been made with a view of determining this amount it must be neglected and cannot be included in this discussion.

During the flood of 1905 discharge measurements were made at Sarras but there was not time to complete the equipment of a permanent gauging station before the flood rose, and the temporary hawsers were carried away in the latter part of August. Specimens of water were collected regularly so long as measurements continued but they were not taken at sufficiently numerous points in the section to give reliable mean values in August when the velocity was considerable.

SEDIMENT IN SUSPENSION IN NILE WATER AT SARRAS IN 1905.

Date	Amount taken litres	Parts per million.			Remarks
		Organic	Mineral	Total	
June 22..	5·1	2·7	18·9	21·6	
„ 28..	5·2	2·2	8·4	10·6	
„ 30..	5·1	2·8	8·4	11·2	
July 2..	5·1	2·6	8·7	11·3	
„ 4..	5·2	3·0	9·0	12·0	
„ 5..	5·1	3·0	9·5	12·5	
„ 8..	5·0	4·9	9·9	14·8	
„ 10..	5·1	4·4	9·0	13·4	
„ 12..	5·0	3·3	9·2	12·6	
„ 14..	5·2	2·5	8·9	11·4	
„ 16..	5·1	3·7	12·9	16·6	

SEDIMENT IN SUSPENSION IN NILE WATER AT SARRAS IN 1905—*continued.*

Date.	Amount taken litres	Parts per millions			Remarks
		Organic	Mineral	Total	
July 18...	5.0	3.5	16.5	20.0	
„ 20...	5.1	4.2	22.2	26.5	
„ 22...	5.0	4.6	20.9	25.5	
„ 24...	5.2	3.8	20.3	24.1	
„ 26...	5.1	6.6	42.6	49.2	
„ 28...	5.2	13.5	86.2	99.6	
„ 30...	5.1	38.2	287.3	325.5	
Aug. 2...	5.2	56.7	580.2	637.0	
„ 4...	5.0	34.4	379.5	413.9	
„ 6...	4.4	104.7	990.4	1095.1	
„ 8...	5.6	83.7	782.2	865.9	
„ 12...	5.1	85.8	628.4	714.2	
„ 14...	5.1	91.0	622.9	713.9	100 metres from East Bank.
„ 14...	2.8	23.5	217.2	240.7	40 „ „ „ „
„ 16...	5.1	78.0	738.6	816.6	100 „ „ „ „
„ 16...	1.8	17.3	129.0	146.4	190 „ „ „ „
„ 16...	0.9	24.4	191.1	215.6	40 „ „ „ „
„ 18...	4.2	107.2	837.1	944.3	97 „ „ „ „
„ 18...	1.9	28.0	176.8	204.9	47 „ „ „ „
„ 20...	5.2	123.7	1358.2	1481.9	110 „ „ „ „
„ 20...	1.9	28.7	167.2	195.8	200 „ „ „ „
„ 20...	1.8	28.6	229.1	257.7	50 „ „ „ „
„ 22...	5.1	109.6	889.8	999.4	40 „ „ „ „
„ 24...	4.3	113.7	1145.2	1258.9	40 „ „ „ „
Sept. 1...	5.1	56.7	575.9	632.6	40 „ „ „ „

At Nag Hamadi (345 kilometres below Aswan) very interesting observations have been made by Mr. Naus, director of the Sugar Factory at that place, on the amount of silt carried by the Nile at this point in the years 1903-5[1]; samples were taken every 5 days from May to the end of December and after that at longer intervals. The results are of great interest and are given in the following table.

The samples were taken 50 metres from the bank, where the current was strongest.

[1] Kindly communicated by Hon. A. Davey, Director of the Company, to whom I am indebted for permission publish to them.

Sediment carried in suspension in parts per million at Nag Hamadi.

Date.	1903		1904	Mean of month	1905	Mean of month
Jan. 5	...		..		45	
„ 15	...		70	74		42
„ 25	...		..		40	
„ 31	...		77			
Feb. 15	...		..		30	30
„ 20	...		..	39	31	
„ 28	...		39			
Mar. 15	...		44	44		
May 10	...		39		38	
„ 15	...		34		32	
„ 20	...		40	36	36	34
„ 25	...		31		31	
„ 30	...		36		31	
June 5	...		44			
„ 10	...		48		21	
„ 15	...		75	70	28	31
„ 20	...		77		43	
„ 25	...		98			
„ 30	...		78		31	
July 5	...		54		25	
„ 10	...		32		42	
„ 15	...		41	82		36
„ 20	...		42		35	
„ 25	Observations began		64		38	
„ 30	325	Mean of month	260		49	
Aug. 5	351		516		38	
„ 10	467		959		284	
„ 15	534	799	1204	1096	471	673
„ 20	771		1289		764	
„ 25	1233		1418		961	
„ 30	1436		1188		1521	
Sept. 5	1427		942		1774	
„ 10	1258		827		1627	
„ 15	1114	1154	709	764	1488	1434
„ 20	1092		714		1411	
„ 25	1132		692		1318	
„ 30	994		640		988	
Oct. 5	832		532		897	
„ 10	776		503		779	784
„ 15	671	634	403	401	675	
„ 20	573		327		Observations ceased.	
„ 25	496		382			
„ 30	458.		259			
Nov. 5	341		197			
„ 10	314		166			
„ 15	314	290	143	155		
„ 20	287		147			
„ 25	260		122			
„ 30	221		..			
Dec. 5	181		89			
„ 10	162		78			
„ 15	149	141	75	67		
„ 20	133		71			
„ 25	128		59			
„ 30	93		31			

Numerous determinations of material in suspension have been made near Cairo but these are not much more satisfactory than those on the upper Nile since it appears that a single surface sample alone was taken on each date.

Mustafa Magdali[1] determined the amount of material in suspension at Cairo once a month for 10 months from August 1849 to July 1850, but the amounts, especially those for August and September appear much too high. The quantity of water taken as a sample is not mentioned nor is the method of collection describeb, but doubtless it was from the surface only; organic and inorganic residues are also

MATTER IN SUSPENSION([2]) IN PARTS PER MILLION.

Date.			Organic.	Inorganic.	Total.
January	9	1850	82	142	224
February	19	„	176	50	226
March	21	„	112	34	146
May	13	„	66	48	114
June	15	„	14	32	46
July	17	„	48	58	106
August	28	1849	1188	4286	5474
September	23	„	1179	3941	5120
October	17	„	816	1109	1925
November	16	„	726	510	1236

described as combustible and incombustible, this apparently being the only method of determination employed.

Samples were again taken at Cairo on the 15th of each month in 1887 and these were examined by M. Mathey[3] (ex-chimiste du laboratoire municipal de la Ville de Paris) with the following results:

SUSPENDED MATTER.

Month	Organic	Mineral	Total[4]	Parts per million
January	0.1928	1.4528	1.6456	165
February	0.1673	1.2168	1.3241	132
March	0.0692	0.6598	0.7290	73
April	0.0604	0.4377	0.4981	50
May	0.0957	0.4003	0.4964	50
June	0.8342	0.5929	1.4271	143
July	0.9174	0.9018	1.8192	182
August	1.8271	10.5223	12.3492	1235
September	0.6148	4.9189	5.5337	553
October	0.4754	3.4282	3.9036	390
November	0.3475	2.9884	3.3359	334
December	0.1936	2.7208	2.9144	291

[1] "Mem. Inst. Egypt." tome I. p.173-6 Paris 1862.

[2] Air dried only.

[3] "Annales de la science agronomique" tome II, p. 340.

[4] Perhaps decigrams per litre, but not definitely stated; if grams per litre the parts per million are abnormally high in comparison with all other results.

In 1874-5 samples were taken monthly at Cairo and submitted for examination to Dr. Letheby.

MATERIAL IN SUSPENSION IN PARTS PER MILLION.

Date	Organic	Mineral	Total	Date	Organic	Mineral	Total
Jan. 23, 1875..	19	148	167	July 10, 1874	91	87	178
Feb. 12 „ ..	11	115	126	Aug. 12 „	184	1307	1492
Mar. 15 „ ..	7	46	53	Sept. 20 „	59	483	543
April 15 „ ..	5	61	66	Oct. 12 „	46	332	378
May 13 „ ..	9	38	48	Nov. 12 „	37	307	344
June 8, 1874..	8	61	69	Dec. 12 „	19	270	289

In 1888-9 Mr. Pollard examined samples taken twice monthly for twelve months at Cairo.

MATERIAL IN SUSPENSION IN PARTS PER MILLION.

Date	Total	Date	Total
Jan. 5, 1889	136	June 23, 1888	23
„ 19 „	128	July 7 „	14
Feb. 2 „	102	„ 21 „ .. .	60
„ 16 „	87	Aug. 20 „	1631
Mar. 2 „	60	Sept. 1 „	2312
„ 16 „	50	„ 22 „	1636
April 6 „	59	Oct. 12 „	1056
„ 20 „	40	Nov. 3 „	813
May 4 „	32	„ 17 „	483
„ 18 „	17	Dec. 8 „	262
June 8, 1888	33	„ 22 „	209

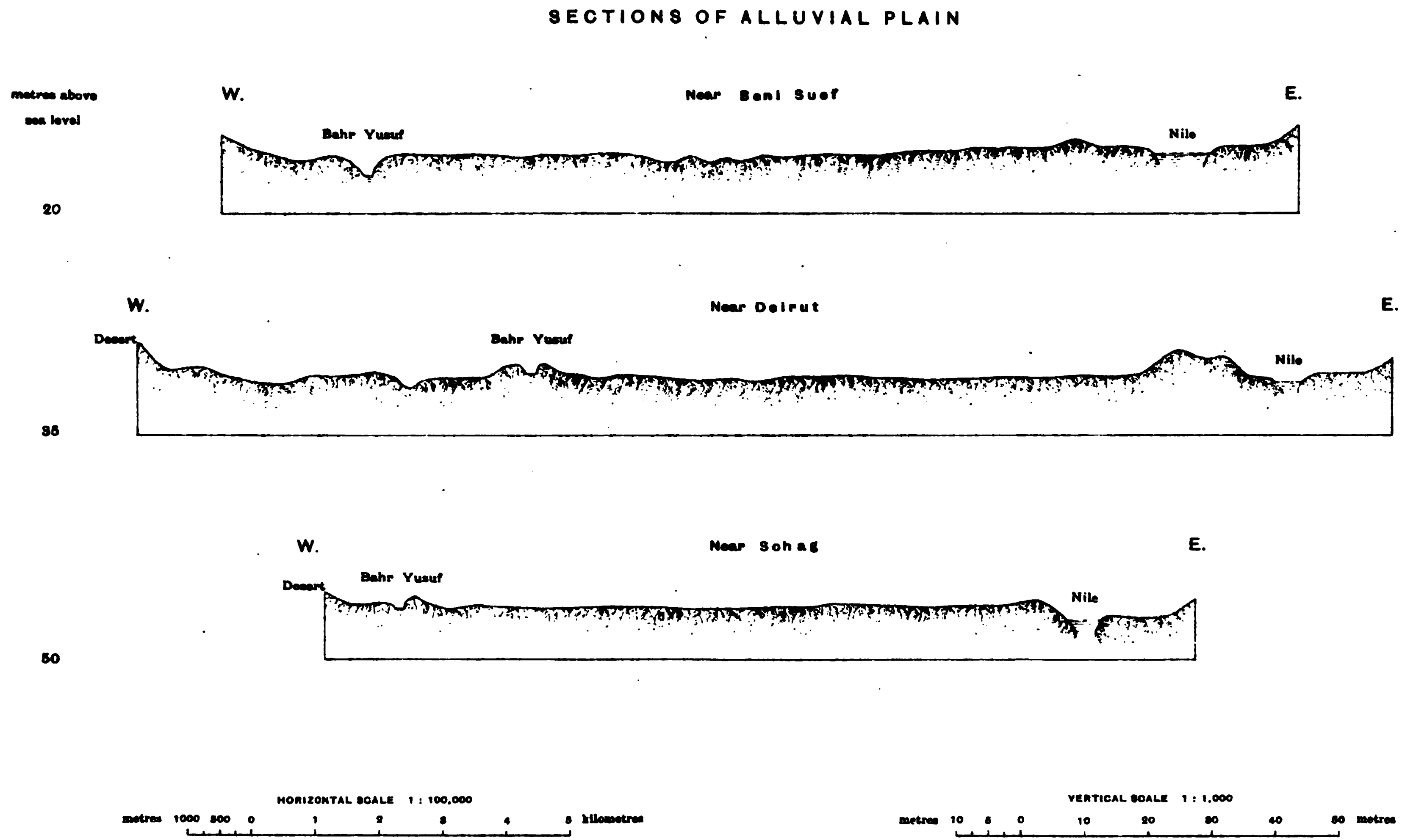
Droop Richmond[1] determined the amount of suspended matter from March to September and in August took samples on six occasions which show well the rapid increase of silt with the rise of the flood.

MATERIAL IN SUSPENSION IN PARTS PER MILLION.

Date	Total	Date	Total
1891		1891	
Mar. 25	38	Aug. 15	1886
April 28	45	„ 22	1343
May 26	14	„ 24	1604
June 29	66	„ 28	1886
July 25	313	Sept. 4	1477
Aug. 1	298	„ 15	1516
„ 11	785	„ 31	1604

[1] Chemistry of River Waters.

PLATE XXXIX.



SURVEY DEPT. CAIRO.

Dr. Mackenzie determined the material in suspension for 2 years with the following results:—

SEDIMENT IN NILE WATER.

Month	Parts per million 1896	Parts per million 1897	Remarks
			Probably dried at 100 C.
January	290	490	Samples taken on the 15th of each month from centre of river one metre below surface opposite Giza village.[1]
February	250	279	
March..	200	190	
April	160	140	
May	130	140	
June	170	130	
July	100	110	
August	1000	1740	
September	1660	1630	
October	1350	1000	
November	900	600	
December	630	350	

Sir W. Willcocks remarks[2] that these specimens of Nile water were unfortunately taken downstream of a place where the Nile was eating away a sandy island so that the results are probably not a true gauge of the matters held in suspension in ordinary Nile water. Certainly the results for October seem to be abnormally high.

Collecting there results we obtain for the amount of suspended matter in Nile water at Cairo in parts per million:—

Month	(1)	(2)	(3)	(4)	(5)	(6)	(7)
January ..	224	167	165	132	..	290	490
February ..	226	126	132	95	..	250	270
March.. ..	146	53	73	55	38	200	190
April	..	66	50	50	45	160	140
May	114	48	50	25	14	130	140
June	46	69	143	28	66	170	130
July	106	178	182	37	313	100	110
August ..	5474	1492	1235	1631	1500	1000	1740
September ..	5120	543	553	1974	1532	1660	1630
October ..	1925	378	390	1056	..	1350	1000
November ..	1236	344	334	648	..	900	600
December ..	..	289	291	235	..	630	350

[1] Journal Khedivial Agricultural, Society Vol. I, pp. 99-102.

[2] Egyptian Irrigation, 2nd E l. p. 12.

(1) Mustafa Magdali, Aug. 1849-July 1850. "Mem. Inst. Egypt." tome I, p. 173-6, Paris 1862.
(2) Letheby, June 1874-May 1875. Min. Proc. Civil. Eng., vol. LX, p. 367.
(3) Mathey, Jan-Dec. 1887.
(4) Pollard, June 1888 May 1889.
(5) Droop Richmond, Mar.-Sept. 1891, Chemistry of River Waters.
(6) Mackenzie, Jan-Dec. 1896, Jour. Khed. Agric. Soc., Cairo, I pp. 99-102
(7) Mackenzie, Jan-Dec. 1897, loc. cit.

Droop Richmond made also a few determinations at places up-stream of Cairo for which the results are as follows: —

Probably dried at 100 °C.

Date	Place	Parts per million	Date	Place	Parts per million
1891					
August 16..	Aswan ..	1049	Sept. 13 ..	Assiut ..	1498
„ 27..	Beni-Suef ..	1481	„ 14 ..	Minia.. ..	1522
„ 22..	Wasta ..	1395	„ 14 ..	Beni Suef ..	1473
„ 22..	Atfeh.. ..	1472	„ 15 ..	Cairo	1516
„ 22..	Helwan ..	1436	Aug. 15 ..	Wadi-Halfa	1121
„ 22..	Cairo	1342	„ 26 ..	Cairo	1604

In discussing these determinations of suspended matter from samples collected at Cairo, the amounts for the months November-July are probably fairly accurate, though Mackenzie's results for November seem high, perhaps for the reason given by Willcocks. Those of August, September and October are certainly of unequal value. At this season the river is flowing with a velocity of about 2 metres per second and eddying currents are carrying upward towards the surface from the lower portions of the mass of water silt which gradually sinks again in the less disturbed parts; a sample of water collected from one of these upward currents may easily contain a far larger amount of silt in suspension than the average load of the river at that time. Only such data as are derived from samples taken at numerous parts of the section on the same date can be reliable and these should be taken as frequently as possible during the flood period.

When it is remembered that the transporting power of a river varies as the *sixth* power of its velocity, that doubling velocity increases the transporting power 64 times, it will be realized that in a large river full of eddies and currents moving with varying velocities the load of material in suspension must vary largely both vertically and horizontally. Even when numerous samples from a well distributed series of points in a river-section have been taken, the bottom load has not yet been considered. This is the coarser sand which is partly carried in suspension by the bottom layers of water and partly rolled along the bottom in the form of sand waves; it forms a considerable proportion of the total load carried by a river but is unaccounted for in all the above determinations.

From the foregoing discussion then it would appear that of some 2100 parts per millions of material which is carried past Berber as a maximum, some 1,600 parts pass Cairo in years of average flood;

without laying stress on these figures, which are but approximations and take no account of the bottom-load, they show that a considerable amount it is deposited in the river bed between these two points, in consequence of loss of velocity as the more gentle slopes of the lower reaches of the river are met with. In the winter months however the reverse takes place and much of what has been deposited is taken up as the river falls for the Blue Nile ceases to supply silt-laden water and erosion takes place throughout the lower reaches.

While it is the finer silt which is deposited in the irrigation basins, on the shelving banks of the river and on such parts of the flood-plain as are annually flooded, it is the bottom load which is deposited in the bed of the river itself, and this consists of the coarser sand which the current cannot carry so readily as the finer material. If the Nile mud is treated by levigation so as to remove the finest particles of clay and sand the residue is a fine whitish grey sand such as is seen forming sand banks in the Nile wherever the conformation of the river is such that the velocity of the flood current is reduced at that point.

In this Aswan-Cairo reach of the Nile then we have to do with a river which is flowing with a low slope through an alluvial plain which it has formed and which, if uncontrolled, it annually floods, depositing on the flood-plains part of its load of silt as the velocity of flood water is diminished. This is the first time in the study of the Nile basin that this particular form of river development has been exhibited. In the Bahr el Jebel near Mongalla deposition of suspended material takes place but owing to the frequent bifurcation (anastomosis) of the stream the velocity is soon reduced and the silt is deposited in the side channels, backwaters, and lagoons, so that in the lower reaches no increase of the flood-plain is taking place. The Blue Nile and Atbara are still, or have but recently ceased, cutting their channels, and are not forming alluvial plains, while the Dinder and Rahad, which are depositing (see p. 225) have not carried the process far; between Khartoum and Aswan the fall is sufficient to maintain sufficient velocity and, as has been shown above, the river in this reach is probably eroding its bed.

North of Aswan the Nile exhibits all the characteristics of a river in its plain tract although it has been of late years to a considerable extent trained and controlled to meet the requirements of irrigation.

Its valley is due in all probability to crustal fracture and movement, and was not eroded by the river itself, but in it has been laid down during a long period the bed of alluvial deposit which has now a thickness of from 10 to 18 metres, and overlies a deposit of coarse yellow sands and gravels which are probably of marine and fluvioma-

rine origin. As a river flows down the gentle slope of its flood-plain unrestrained by rocky walls or banks of hard material, its path is a series of curves; any obstacle will deflect the current causing the river to swing from side to side, and erosion will take place on the outer side of the curves while on the inside material will be newly deposited.

In this way curves become accentuated and form what are known as meanders which both work down-stream and also across the flood-plain of the valley. The sharp curves modify their shape rapidly but the general swing of a length of the river from one side of the flood-plain to the other may extend over long periods of time, In this swing from side to side of the valley the whole material is gradually sorted and approximately levelled.

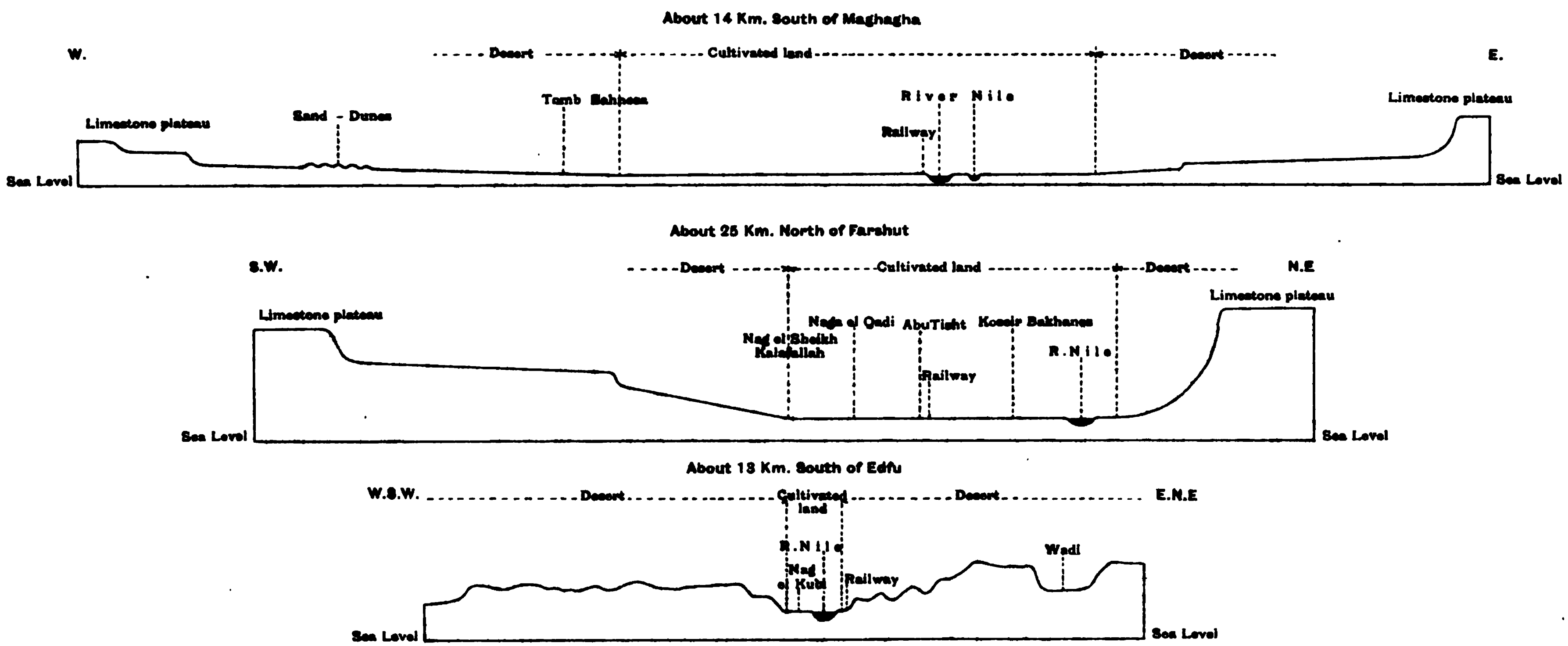
These meander curves often become so sharp that the opposite ends of a curve approach closely till only a narrow neck divides them ; if this neck is inundated in flood the slope is often sufficient for a small channel to be cut across the neck, and this rapidly deepens until it becomes the main channel; when this has taken place both ends of the former channel rapidly become shallow as silt is deposited in the slack water, and thus the former river bed becomes a semicircular lake known in the Mississippi valley as an "oxbow curve."

In Egypt where all the alluvial plain is under cultivation, gcod examples of such cut-off bends are seldom seen, but they are frequent in the Bahr el Jebel, and along the lower course of the Rahad and Dinder (Plate XXVI) they also occur.

Where a silt-laden river inundates its flood-plain the greatest amount of deposition takes place along the banks where the velocity is first checked, so that these are raised, and beyond them the country slopes away from the river; this is well shown in Upper Egypt were there is a difference of up to 3 metres in height between the land by the river and that along the edge of the desert. (Plate XL).[1] Branches which leave the main stream flow along this lower country which in the natural state of the valley contains swamps and lagoons which are filled with water in the flood season and being imperfectly drained remain as waste tracts covered with swamp-loving plants. At an earlier period of the Nile valley's history there must have been a belt of such land along the edge of the western desert which bounds it, and here and there traces of it still exist ; the present Sohagia canal probably occupies the line of one of the branches of an earlier time, and the Bahr Yusef is certainly one, as it has all the characteristics of a stream meandering in its flood-plain.

[1] See also Egyptian Irrigation. Plate IX.

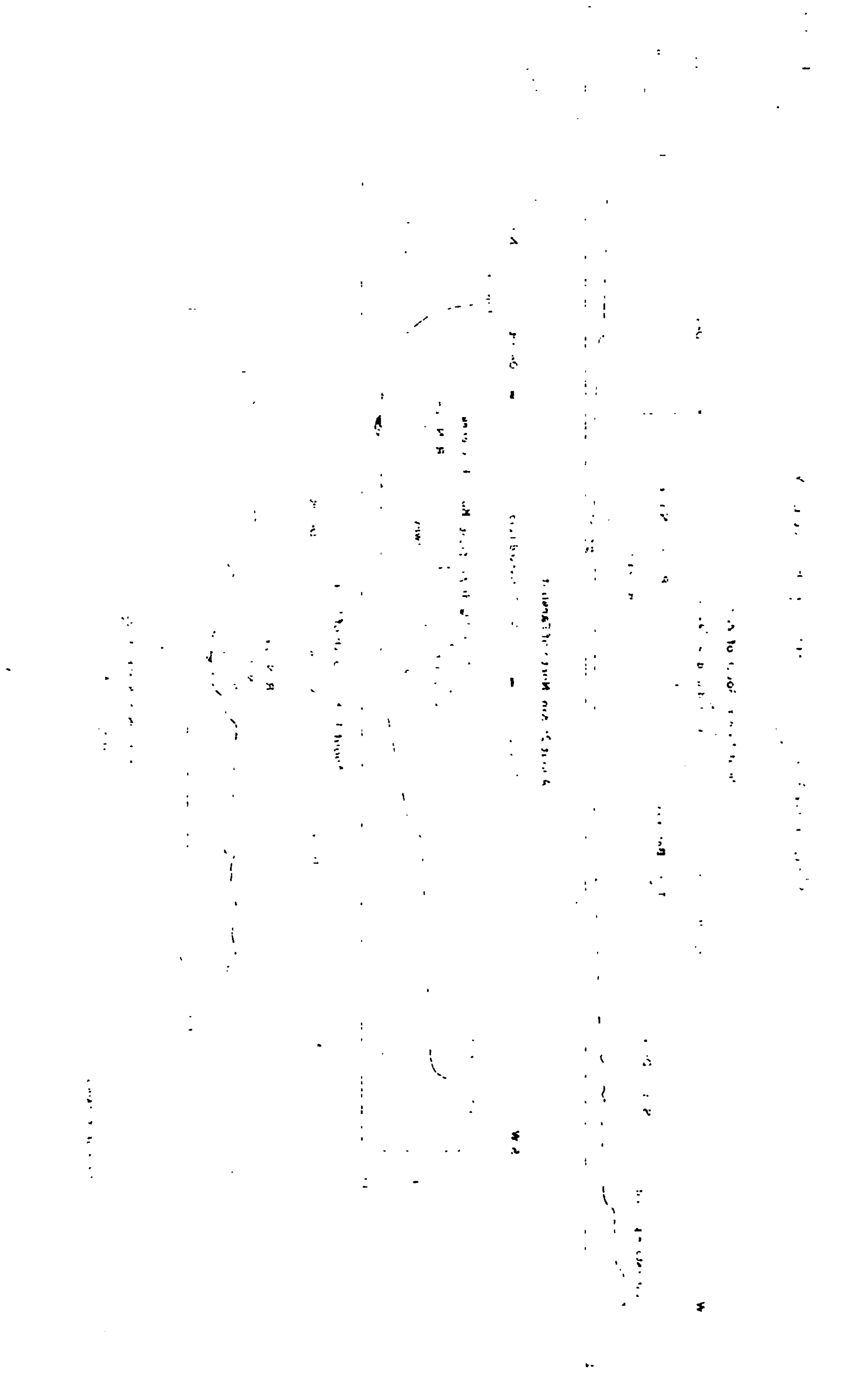
SECTIONS ACROSS THE NILE VALLEY



HORIZONTAL SCALE 1 : 800,000

VERTICAL SCALE 1 : 20,000

SURVEY DEPT. CAIRO.



Throughout almost the whole of its course the Nile in Egypt flows on the eastern side of its valley and while the earth's rotation has played its part in deflecting the stream to the right, the action of the wind has probably been still greater. At low stage the river lies well within its bed and but little erosion of the banks takes place, but at flood this proceeds rapidly and at this season, July, August, September, the wind has a marked westerly component which drives the water on to the right or eastern bank.

The Nile like every other river that has formed alluvial flood-plains works from side to side of its valley as above described and has left clear traces of its action on either side, but it is not necessary to conclude from this that in early times the river filled the whole valley.[1] The deposits of Nile mud containing shells of species now living in the Nile lie above the present Nile level, 30 metres near Wadi Halfa, and at Derr, at lower levels at Silsila and other points of the valley, and about 6 or 8 metres near Cairo; these are the remains doubtless of an earlier alluvial flood plain through which the river has cut down to a point below its present level since for at least 5000 years it has been raising its flood plain by its annual deposit of silt.

The resultant effect of this deposition during flood and erosion during the falling stage of the river has been to raise the river-bed between Aswan and Cairo at the average rate of about 10 centimetres per centnry during the last 2000 or 3000 years, and certainly for a much longer pericd.

Evidence for this depends mainly on the levels of ancient floods which are recorded at Aswan and at the temple of Karnak.

The nilometer at Elephantine is on the east side of the island and opposite to the town of Aswan at the foot of the cataract. To-day it consists of a single stairway of 52 steps, parallel to the quay-wall, after which it turns to the east and opens on to the river through a doorway in the wall. At the time of the visit of the French expedition in 1799 not only did this portion exist but also an upper stairway about 20 metres long leading westwards into a small room through which the Nilometer was reached. All this upper portion has now disappeared except the bottom seven steps which are partially covered by the wall of a modern water-wheel. Of the scales for recording the heights of the Nile, two are on the east wall, viz., the arabic scale of 1869 divided into pics and qirats, and the marble scale now in use which is divided metrically and numbered to show the height above mean sea level; on the west

[1] Maspero, "Dawn of civilization," London 1896, p. 6. Petrie, "Ten years digging in Egypt," London 1892, p. 75.

wall are the remains of another Arabic scale, and of one numbered with Greek numerals which is that which was used in late Egyptian times.

This scale is cut into the wall in lengths of one, two, or three cubits, each cubit being further subdivided into 14 half palms. The cubits themselves are numbered with Greek numerals placed beside the scale, but in the case of the lowest cubit which it was possible to measure on April 15 1896 the demotic numerals for 17 as well as the Greek were visible.

The highest portion of the scale is a single cubit, the twenty seventh, but no numeral is now legible; the next is a single cubit with the numeral 26 in greek letters plainly cut; below this is a single cubit marked 25, which is followed by a length of two cubits numbered respectively 24 and 23. 1·8 metres further north is a length of two cubits, 22 and 21 while 2·99 metres from the north end of the north and south portion is a length of three cubits with the numbers 20 and 19 ; beyond this is a short length of a scale which does not belong to the one now being described and perhaps belongs to an earlier one. 2·35 metres beyond the landing and near the outer face of the quay wall is a length of one cubit beside which the demotic numeral for 17 can be read.

The lengths of the cubits are given in the following table and the height of the top and bottom of each above sea level shows the very moderate accuracy with which those who cut them were satisfied.

No.	Cubit.	Length.	Height above sea level of the top and bottom of the cubit.	
		metres	metres.	
I.	XXVII	·541	92.310 91.769	.... error in level 4 cm.
II.	XXVI	·545	91.729 91.184	.... error in level 4 cm.
III.	XXV	·520	91.144 90.624	....
IV.	XXIV	·5185	90.624 90.106	....
	XXIII	·5185	90.106 89.587	.... error in level 5 mm.
V.	XXII	·530	89.582 89.052	....
	XXI	·530	89.052 88.522	....
VI.	XX	·511	88.522 88 011	....
	XIX	·511	88.011 87.500	....
	XVIII	·510	87.500 86.990	.... error in level 0·5 cm.
VII.	XVII	·520	86.925 86.405	....
Mean length of a cubit		0·5232	....	....

Though the scales are somewhat roughly cut there is no great difficulty in measuring them with some accuracy and the above table shows that there are as usual considerable differences in length between the different cubits.

The lengths of cubits 18 to 24 differ considerably from the length of the same cubits as measured in 1799[1] nor does the mean value of 0·527 metre which is there shown as exactly given by each portion of the scale measured, agree with that obtained by the foregoing measurements, viz., 0·523, nor with that obtained by Sir Gardner Wilkinson[2] viz: 0·5239 metre. He does not state how many cubits were measured to get this mean, but says that the measurements were taken carefully by himself.

Every precaution was taken in making the measurements given in the table above; each cubit was separately measured and the horizontal line from the bottom of one part of the scale to the top of the next along the stairway was determined by means of a long straight edge and a spirit level. On the wall of the stairway are the remains of Greek inscriptions dating from the reigns of several of the Roman Emperors and giving the year of his reign and the height of the Nile flood.

From these[3] it is clear that about 100 A.D. the Nile often rose to 24 and sometimes above 25 cubits on the Nilometer scale; so that the high floods of that time reached the level of 91 metres above sea-level. To day they reach 94 metres as in 1874 or 3 metres above the level of about 1900 years ago, corresponding to a rise of the bed of 0·16 metre per century at this point. If the mean flood level of the last 36 years is taken the height becomes 93 metres and the rise 0·11 metre per century.

At Karnak in 1895 M. Legrain found a series of 40 high Nile levels marked on the quay wall of the great temple. They date from about 800 B.C. and the mean altitude given by them for a high Nile is 74·25 metres above sea level, while that of to-day is 74·93, showing a rise of the river-bed of 2·68 metres in 2800 years or at the rate of 0·096 metres per century.[4] It is this rise of the river bed, and consequently of the subsoil water-level which is continually changing the conditions of foundations of buildings which were built in these ancient times. Built high above infiltration level, the secular rise of the river-bed at last raises the water-level until these stone constructions originally intended

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1 "Expédition française" 2nd Ed., Paris, 1825, t. 6, p. 13.
2 Manners and Customs of the Ancient Egyptians, vol. II, p. 382.
3 Borchardt, "Nilmesser und Nilstandmarken. Abhandlungen der kgl. Preuss, Akad. d. Wissensch, zu Berlin," 1905.
4 Ventre Pacha. "Crues modernes et crues anciennes du Nil." Aegypt. Zeitsch., 1896, p.95. These levels need sliпht correction which will slightly increase the rate of rise.

to stand dry are now wetted annually and at last may pass below the permanent water level of the soil. In this way the foundation courses of the columns of Karnak Temple have gradually deteriorated by the combined action of subsoil water and the acids derived from the decomposition of organic matter from the coptic village which in past centuries filled the temple, until in September 1900 the foundation blocks of one column were crushed by the superincumbent weight and in its fall it overthrew others.

The nilometres of Ancient Egypt are of great interest to the student of the Nile as they furnish a record which extends back for about 5000 years.

Remains of Nilometers, or records of the heights reached by the Nile in flood in ancient Egyptian times still exist at the following places:—

Place	Remarks
SEMNA........	Flood levels of Middle Empire.
KUBOSH.......	2 copies of a cubit numbered 21 cut on an old quay wall.
TAIFA.........	Two cubits cut on an old quay wall.
PHILAE.......	3 nilometer scales of about 17 cubits in the nilometer stairway. Part of a rudely cut scale in the west stairway. An inscription recording the height of an unusually high Nile on the gateway N.E. end of the island.
ELEPHANTINE..	Nilometer of 28 cubits. Fragment of an old nilometer at Aswan. Inscriptions of Roman time recording high Niles.
KOM OMBO....	A nilometer, but it is not now accessible.
SILSILA.......	Flood mark
EDFU.........	Nilometer, of which 6 cubits can be seen, the highest being numbered 20
ESNA.........	Nilometer, of which 10 cubits can be seen, the highest being numbered 21.
KARNAK......	Numerous Flood level marks of late New Empire.
LUXOR.......	Nilometer of which 7 ½ cubits can be seen.
TEHNE........	Inscriptions.
KOM EL GIZA..	Nilometer.

and they have been discussed by Dr. L. Borchardt in his paper on "Nilmesser und Nilstandmarken," of which he has kindly given the following summary.

" The height above sea-level of corresponding points of the ancient nilometers in Egypt and Nubia have been determined with the aid of the bench-marks of the Irrigation Department and the zero points of the nilometer scales were found to lie in a line inclined to the north. In Nubia the line is sensibly parallel to the water-slope, but north of Aswan it is considerably less inclined than the flood-slope; consequently a flood was indicated by a higher reading on the nilometer at Aswan than on that of Roda at Cairo. This explains the statement found in the egyptian inscriptions and the works of the greek and roman authors, that the Nile in very good years rose 28 cubits at Elephantine, 21 cubits at Koptos, 14 at Roda and 7 in the Delta. From the slope of

the line determined by the zero points of the nilometers, the altitude of the zero of the ancient nilometer at or near Roda may be approximately obtained, and after calculating the secular rise of the bed it can be deduced that the flood levels about 3000 B.C. which are recorded on the Palermo stone and the data concerning Nile floods given by the greek and roman authors agree well with those of to-day."

It is much more difficult to obtain any satisfactory estimate of the rate of increase of the flood-plain. The rate of deposit varies so greatly at different points and in so few is there any satisfactory means of determining the period during which any given thickness has been laid down that the results which have been obtained are at the best but very rough approximations. Horner[1] in his researches at Memphis found the base of the colossal statue of Ramses II to be 2·90 metres below the present ground level corresponding to a rise of about 9 centimetres per century. At Heliopolis 10 kilometres north of Cairo the base of the obelisk dating from 1850 B. C. is 1·65 metres below the present level; Ventre Pasha[2] estimates the rise at about 20 centimetres per century, or by another estimate based on the rise at Roda island at Cairo 14·3 centimetres;[3] at Naukratis Petrie found evidence of a rise of 12 centimetres per century. Borchardt found at Abu Gurab and at Abusir a rise of 13·5 centimetres per century. These results seem to show that the land has risen slightly faster than the river bed but evidence is insufficient to establish the matter; at all events it may be confidently stated that in the future with the greater part of Egypt under perennial irrigation, and receiving not annual inundation but water supplied throughout the year, the river bed will rise more rapidly than the flood plains.

Hydrography.—In this reach of the river its waters are required for the irrigation of the fertile flood plains, and so large an amount is taken off for this purpose by numerous canals, that we no longer have to do with a river under its normal conditions, while the Delta Barrage and the more recently constructed Assiut Barrage raise the water-level up-stream of them in low stage, and consequently also the level of the water-table in the soil of the valley. Few observations have been made on this latter point although it is a matter of considerable importance.

The Roda gauge, from its long series of observations, would be of inestimable value if its records were trustworthy, but, unfortunately, this

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1 Phil. Trans. Roy. Soc. 1855.
2 Bull. Inst. Egypt., Cairo 1890.
3 "Zeitsch. für Aegypt Sprache," Leipzig, 1896, p. 105.

has not always been the case.[1] For many years past, at least for two centuries, the sheikh of the nilometer has been in the habit of recording the height of the Nile by marks on the wall, and by the steps of the well in which the nilometer column is erected, instead of by the scale of cubits which is cut on the column. The cubits which are used by him are on the average 0·54 metre in length from the first to the six-teenth cubit inclusive, 0·27 metre from the seventeenth to the twenty-second cubit inclusive, and 0·54 metre for the twenty-third and all higher cubits.

The values given by Chélu[2] and by Willcocks[3] for the lengths of the cubits differ slightly. Cubits 14, 15, and 16 have been given by the latter as 0·48 metre to 0·49 metre only. However, the method of observation was certainly not one of great accuracy, and no considerable error will be introduced into the discussion of the yearly maxima if the values given by Willcocks are taken as being correct.

Unfortunately, no original documents earlier than 1873 A.D. now exist in the Ministry of Public Works, Cairo, by which these readings may be verified. The series published by Ali Pasha Mubarik,[4] which is supposed to have been taken from original documents, is given for Mohammedan years, and when the beginning of a year, the 1st Moharrem, falls near the date when the Nile is highest, there is some doubt to which year the recorded maximum belongs, as no day of the month is mentioned. From 1846 to 1878, however, there was a series of readings at the Delta Barrage, 25 kilometres down-stream of the Roda gauge, which serves as a control. It will then be best to take the maximum readings as given by Tissot,[5] where the date of the maximum reading recorded is given for each year.[6] There is another series from 1737 A.D. to 1800, which appears to have been recorded under similar conditions, the range being much the same; and when the readings are converted to metres in the same way as those from 1825 to 1872, the mean maximum is 7·02 metres for the former as compared with 7·17 metres for the latter.

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[1] See also "Déscription de l'Egypte," vol. 18, Paris 1825; Manoug, "Données utiles sur la crue du Nil," Alexandrie 1882; Ardagh, Proc. R.G.S., 1889, p. 28; Manoug, Proc. R.G.S., 1889, p. 245.

[2] "Le Nil, le Soudan et l'Egypte," pp. 84 and 87, Paris 1891; but the values on these two pages do not agree.

[3] Egyptian Irrigation, App. V, p. 472. London, 1899.

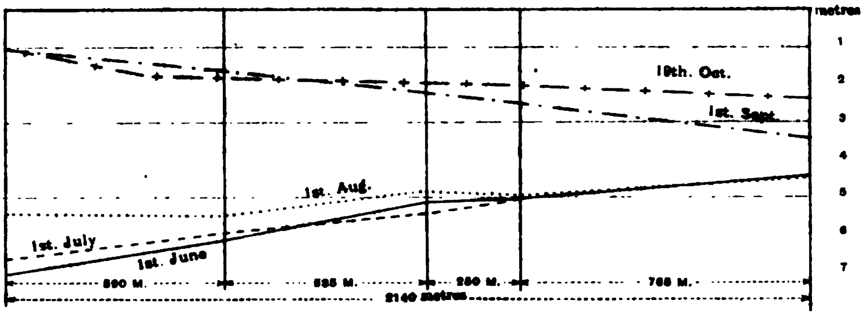
[4] "El Khitat el Taufikia el Gedida li Misr el Kahira," chap. XVIII. Cairo 1306 A.H.

[5] "Statistique de l'Egypte," Cairo, 1883.

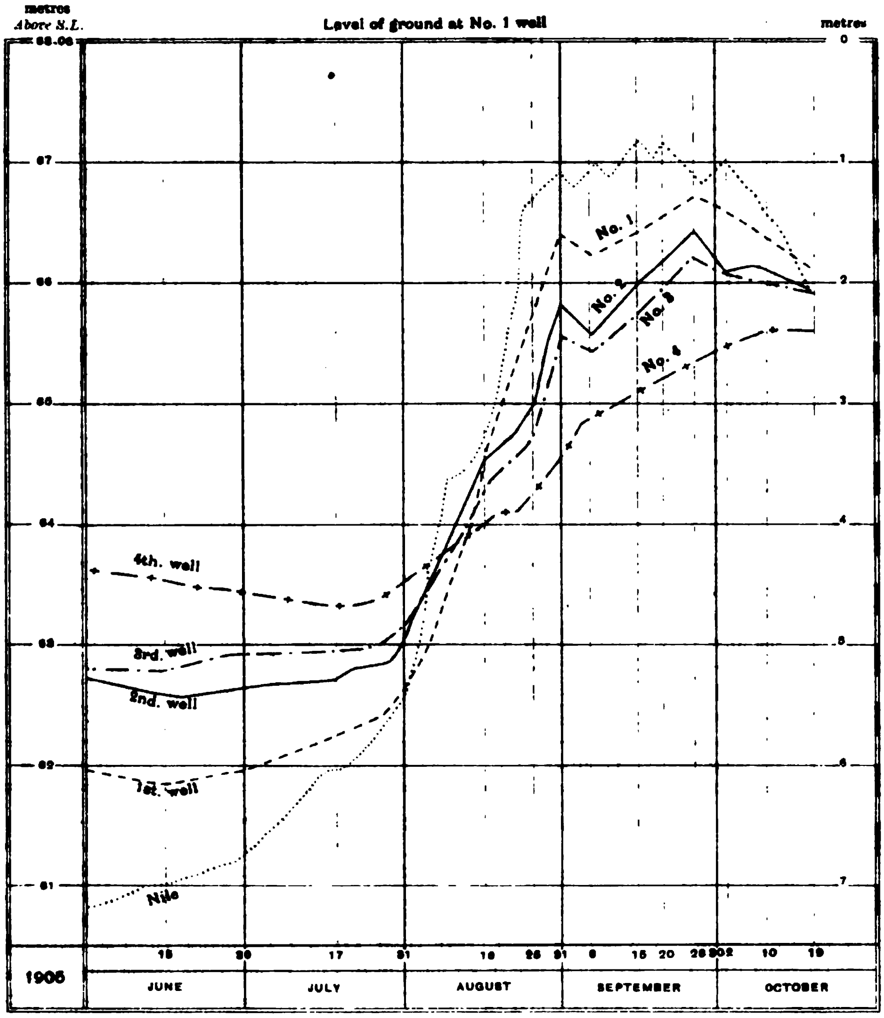
[6] It should be mentioned that the original observations were made according to the Coptic (Julian) calendar, and Ali Pasha Mubarik has converted them into the corresponding Mohammedan years. Here, however, an error has crept in. No Nile maximum occurred in the year 1270 of the Hegira, one falling at the end of 1269 A.H., and the next at the beginning of 1271 A.H., though he has recorded that for 1271 A.H., as if it belonged to the year 1270 A.H. and so on. Thus all the Nile floods from 1851 to 1862 are given a year too early; but by recording the flood of 1862 to both 1278 A.H. and 1279 A.H., the years after this have been made correct.

Sec 3.·/

HEIGHT OF THE WATER-TABLE AT NAG HAMADI IN 1905



COMPARATIVE DIAGRAM OF WATER LEVEL OF THE NILE AND OF FOUR WELLS AT NAG HAMADI



SURVEY DEPT.

The Delta Barrage[1] records are less ambiguous. They extend from 1846 to 1872, and were kept daily for the whole year, and not for the flood only. No originals of these apparently exist in Egypt now but the maxima are given in "Statistique Générale de l'Egypte,"[2] and copies of all the observations were sent by Stone Pasha in 1880 to Colonel Donnelly, by whom they were given to the Science and Art Department, London,[3] but these cannot now be traced.

The daily readings of this gauge for 1846-7-8-9 are given by Jomard and Malte-Brun,[4] and 5-day means for 1846-1861 have been published by d'Arnaud.[5]

Year	Maximum reading		Difference
	Roda gauge[6]	Barrage gauge	
	metres	metres	metres
1846	7·55	7·24	−0·31
1847	7·10	6·48	−0·62
1848	7·70	7·53	−0·17
1849	7·68	7·35	−0·33
1850	6·46	6·13	−0·33
1851	7·77	7·38	−0·39
1852	6·35	6·01	−0·34
1853	7·77	7·76	−0·01
1854	7·55	7·50	−0·05
1855	6·20	5·94	−0·26
1856	7·75	7·46	−0·29
1857	6·48	6·09	−0·39
1858	6·40	6·07	−0·33
1859	6·32	5·90	−0·42
1860	7·67	7·27	−0·40
1861	7·90	7·73	−0·17
1862	7·04	6·65	−0·39
1863	8·11	7·73	−0·38
1864	5·95	5·80	−0·15
1865	7·02	6·52	−0·50
1866	8·31	7·76	−0·55
1867	6·46	6·38	−0·08
1868	5·87	5·83	−0·04
1869	8·40	7·85	−0·55
1870	7·92	7·50	−0·42
1871	7·38	7·48	+0·10
1872	7·65	7·32	−0·33
			Roda-Barrage=0·30

1 A point 25 kilometres below the Roda Nile gauge, where the Rosetta and Damiette branches diverge, the real apex of the Delta.

2 Cairo, 1879. Also see Fritz, "Meteorologische Zeitschrift," 1880, p. 303.

3 "Nature," vol. 25, p. 269, January 19, 1882.

4 Bull. Soc. Géog. Paris, April, 1864.

5 "Mémoires de l'Inst. Egypt.," t. 1, p. 115. Paris, 1861. Also "Zeitsch. f. Allg. Erdkunde" Bd. 14.

6 These are the levels given by Tissot; Willcocks levels are about 0·24 metre higher, and are referred to a zero 12·5 metres above sea-level. The Barrage levels given are above a zero which is said to be 12·05 metres above sea-level. Recent levelling makes the difference between minimum summer supply level at these points 0·30 metre, while the flood levels differ by about 2 metres.

In about seven or eight years the differences are irregular, due perhaps, in some cases to breaching of banks, perhaps to incorrect records, but in three cases the years are those of exceptionally high floods, and thus the twenty or thirty centimetres will not affect the argument. Generally, then, it may be said that as far back as 1846 the data are sufficiently reliable. If, then, the Roda gauge records are so far reliable, it would seem that the others from 1825 to 1845 might also be accepted, though at this time there is no other gauge to confirm them. It happens, however, that from 1825 to 1839 the floods of 1829 and 1834 alone exceed the mean of the maximum readings 1825-1872, and therefore confirmatory evidence that twelve of these years were abnormally low is very desirable. That in 1829 the flood was an exceptionally high one is mentioned by Barker[1] in a letter dated September 1, 1829. Curzon[2] mentions that in 1833 the flood was feeble and late, so that on August 28 9 feet more were needed to ensure an average crop. The years 1836 and 1837 were very low, especially the latter, and this is recorded by Holroyd,[3] who says "the rise of the Nile this year (1837) is less than it has been for five or six years past;" and also by Bowring.[4] Russegger also mentions that the Blue Nile had already fallen at Khartoum 2 feet on August 20, 1837, though it rose again on August 30.[5]

Lefébvre says that of the five years 1839-1843, during which he was in Abyssinia, two had excessive rainfall, while three were deficient.[6] These would correspond with the high floods of 1840, 1841 and 1842, and the low ones of 1839 and 1843, so the numbers of dry and wet seasons seem to be misplaced.

Thus we may accept the Roda maximum gauge-readings as sufficiently accurate for investigating the question of the yearly variation of the Nile flood.

The maximum readings of the Roda gauge 1736-1800, and from 1825 to 1872, together with the differences from the mean maximum and also the five-year means are given below, as well as the same data for the gauge at the Delta Barrage.

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[1] Syria and Egypt under the Last Five Sultans of Turkey, vol. ii, p. 110. London, 1876.
[2] Visits to the Monasteries in the Levant, p. 27. London, 1850.
[3] Egypt and Mohamed Ali Pasha in 1837, p. 28. London, 1838.
[4] A Report on Egypt and Candia, p. 14. London, 1840.
[5] "Reisen in Europa, Asien und Afrika," vol. 4, p. 413. Stuttgart, 1844.
[6] "Voyage en Abyssinie," vol. 3, p. 10. Paris, 1840.

Maximum Readings of Roda Gauge, 1825-1872.[1]

A.D.	Pik. Qirat.	Metres	Difference from mean	Five-year mean Metres +12·50	Five-year difference from mean
1825	19 4	5·96	−1·21	—	—
1826	22 18	7·13	−0·04	—	—
1827	22 8	6·91	−0·26	6·90	−0·27
1828	21 14	6·62	−0·55	7·01	−0·16
1829	24 2	7·87	+0·70	6·98	−0·19
1830	21 8	6·54	−0·63	6·95	−0·22
1831	22 11	6·98	−0·19	6·80	−0·37
1832	21 23	6·73	−0·44	6·73	−0·44
1833	18 23	5·90	−1·27	6·64	−0·53
1834	23 10	7·50	+0·33	6·52	−0·65
1835	19 15	6·08	−1·09	6·36	−0·81
1836	20 17	6·37	−0·80	6·50	−0·67
1837	19 4	5·96	−1·21	6·39	−0·78
1838	21 12	6·59	−0·58	6·71	−0·46
1839	22 9	6·93	−0·24	7·00	−0·17
1840	23 18	7·68	+0·51	7·32	+0·15
1841	24 0	7·83	+0·66	7·38	+0·21
1842	23 14	7·59	+0·42	7·35	+0·18
1843	22 6	6·87	−0·30	7·09	−0·08
1844	22 3	6·80	−0·37	7·08	−0·09
1845	20 15	6·35	−0·62	7·03	−0·14
1846	23 23	7·80	+0·63	7·24	+0·07
1847	23 2	7·31	+0·14	7·47	+0·30
October 2, 1848	24 6	7·96	+0·79	7·54	+0·37
„ 7, 1849	24 5	7·93	+0·76	7·58	+0·41
September 19, 1850	21 20	6·69	−0·48	7·43	+0·26
October 3, 1851	24 9	8·02	+0·85	7·44	+0·27
August 31, 1852	21 8	6·54	−0·63	7·41	+0·24
October 1, 1853	24 9	8·02	+0·85	7·35	+0·18
September 29, 1854	23 23	7·80	+0·63	7·35	+0·18
1855	20 18	6·39	−0·78	7·38	+0·21
October 2, 1856	24 8	8·00	+0·83	7·10	−0·07
September 13, 1857	21 22	6·71	−0·46	6·85	−0·32
„ 6, 1858	21 14	6·62	−0·55	7·16	−0·01
October 27, 1859	21 7	6·53	−0·64	7·19	+0·02
„ 17, 1860	24 5	7·93	+0·76	7·30	+0·13
September 27, 1861	24 16	8·17	+1·00	7·65	+0·48
October 22, 1862	23 0	7·26	+0·09	7·58	+0·41
September 20, 1863	25 1	8·37	+1·20	7·44	+0·27
„ 20, 1864	19 21	6·15	−1·02	7·52	+0·35
October 18, 1865	22 23	7·24	+0·07	7·41	+0·24
September 27, 1866	25 11	8·59	+1·42	6·95	−0·22
„ 11, 1867	21 22	6·71	−0·46	7·45	+0·28
August 27, 1868	19 13	6·05	−1·12	7·65	+0·48
October 11, 1869	25 15	8·68	+1·51	7·45	+0·28
„ 14, 1870	24 17	8·20	+1·03	7·69	+0·52
September 27, 1871	23 16	7·63	+0·46	—	—
October 20, 1872	24 3	7·89	+0·72	—	—
	Mean ...	7·17	Mean ...	7·17	

[1] Readings are taken from "Statistique de l'Égypte," 1883, see also Fritz, Met. Zeit., vol. 8 p. 363. Zero is 12·50 metres above sea-level.

MAXIMUM READINGS OF RODA GAUGE, 1737-1800.

A.D.	Pik. Qirat.	Metres [1]	Difference from mean	Five-year mean metres	Difference from mean
1737	20 18	6·39	−0·63	—	—
1738	24 12	8·09	+1·07	—	—
1739	23 12	7·54	+0·52	7·49	+0·47
1740	24 6	7·96	+0·94	7·72	+0·70
1741	23 8	7·46	+0·44	7·50	+0·48
1742	23 12	7·54	+0·52	7·44	+0·42
1743	22 12	7·00	−0·02	7·42	+0·40
1744	23 0	7·26	+0·24	7·43	+0·41
1745	24 0	7·83	+0·81	7·54	+0·52
1746	23 19	7·71	+0·69	7·51	+0·49
1747	24 3	7·89	+0·87	7·38	+0·36
1748	22 6	6·87	−0·15	7·29	+0·27
1749	21 12	6·59	−0·43	7·31	+0·29
1750	23 5	7·39	+0·37	7·24	+0·22
1751	24 0	7·83	+0·81	7·45	+0·43
1752	23 12	7·54	+0·52	7·43	+0·41
1753	24 3	7·89	+0.87	7·44	+0·42
1754	21 6	6·52	−0·50	7·44	+0·42
1755	23 6	7·41	+0·39	7·55	+0·53
1756	24 0	7·83	+0·81	7·59	+0·57
1757	24 12	8·09	+1·07	7·62	+0·60
1758	24 12	8·09	+1·07	7·56	+0·54
1759	21 19	6·68	−0·34	7·50	+0·48
1760	22 17	7·11	+0·09	7·16	+0·14
1761	23 12	7·54	+0·52	7·02	0·00
1762	20 17	6·37	−0·65	7·25	+0·23
1763	23 6	7·41	+0·39	7·31	+0·29
1764	24 0	7·83	+0·81	7·20	+0·18
1765	23 5	7·39	+0·37	7·19	+0·17
1766	22 12	7·00	−0·02	6·97	−0·05
1767	20 12	6·32	−0·70	7·05	+0·03
1768	23 5	7·39	+0·37	7·00	−0·02
1769	23 12	7·54	+0·52	7·03	+0·01
1770	21 12	6·59	−0·43	6·70	−0·32
1771	23 6	7·41	+0·39	6·89	−0·13
1772	19 16	6·09	−0·93	6·71	−0·31
1773	21 6	6·52	−0·50	6·89	−0·13
1774	22 6	6·87	−0·15	7·07	+0·05
1775	23 12	7·54	+0·52	6·89	−0·13
1776	21 6	6·52	−0·50	7·07	+0·05
1777	22 12	7·00	−0·02	7·26	+0·24
1778	23 6	7·41	+0·39	7·26	+0·24
1779	24 0	7·83	+0·81	7·33	+0·31
1780	23 12	7·54	+0·52	7·07	+0·05
1781	22 6	6·87	−0·15	6·72	−0·30
1782	18 6	5·70	−1·32	6·31	−0·71
1783	18 2	5·66	−1·36	6·04	−0·98
1784	18 12	5·77	−1·25	6·02	−1·00
1785	20 0	6·18	−0·84	6·30	−0·72
1786	22 2	6·78	−0·24	6·57	−0·45
1787	22 17	7·11	+0·09	6·77	−0·25
1788	22 12	7·00	−0·02	6·87	−0·15
1789	22 2	6·78	−0·24	6·80	−0·22

[1] Zero is 12·50 metres above sea-level.

RODA GAUGE, 1737-1800 (*continued*).

A.D.	Pik. Qirats	Metres	Difference from mean	Five-year mean metres	Difference from mean
1790	21 18	6·66	−0·36	6·59	−0·43
1791	21 0	6·46	−0·56	6·43	−0·59
1792	19 14	6·07	−0·95	6·28	−0·74
1793	20 0	6·18	−0·84	6·23	−0·79
1794	19 12	6·04	−0·98	6·21	−0·41
1795	20 21	6·42	−0·60	6·26	−0·76
1796	20 12	6·32	−0·70	6·48	−0·54
1797	20 16	6·36	−0·66	6·56	−0·46
1798	22 23	7·24	+0·22	6·73	−0·29
1799	20 23	6·44	−0·58	—	—
1800	23 2	7.31	+0·29	—	—
	Mean ..	7·02		7·02	

MAXIMUM NILE GAUGE-READINGS AT BARRAGE, 1846-1878.[1]

A. D.	Metres	Difference from mean	Five-year mean	Difference from mean
		metres	metres	metres
1846	7·24	+0·33	..	..
1847	6·48	−0·43	..	..
1848	7·53	+0·62	6·95	+0·02
1849	7·35	+0·44	6·97	+0·04
1850	6·13	−0·78	6·90	−0·03
1851	7·38	+0·47	6·92	−0·01
1852	6·01	−0·90	6·96	+0·03
1853	7·76	+0·85	6·92	−0·01
1854	7·50	+0·59	6·93	0·00
1855	5·94	−0·97	6·95	+0·02
1856	7·46	+0·55	6·61	−0·32
1857	6·09	−0·82	6·29	−0·64
1858	6·07	−0·84	6·59	−0·34
1859	5·90	−1·01	6·61	−0·32
1860	7·27	+0·36	6·72	−0·21
1861	7·73	+0·82	7·06	+0·13
1862	6·65	−0·26	7·04	+0·11
1863	7·73	+0·82	6·89	−0·04
1864	5·80	−1·11	6·89	−0·04
1865	6·52	−0·39	6·84	−0·09
1866	7·76	+0·85	6·46	−0·47
1867	6·38	−0·53	6·87	−0·06
1868	5·83	−1·08	7·06	+0·13
1869	7·85	+0·94	7·01	+0·08
1870	7·50	+0·59	7·19	+0·26
1871	7·48	+0·57	7·30	+0·36
1872	7·32	+0·41	7·35	+0·42
1873	6·45	−0·46	7·28	+0·35
1874	7·98	+1·07	7·28	+0·35
1875	7·15	+0·24	6·85	+0·08
1876	7·50	+0·59	7·20	+0·27
1877	5·18	−1·73	..	..
1878	8·20	+1·29	..	..
Mean ..	.. 6·91		6·93	

[1] Fritz in Met. Zeit., vol. 15, 1880, p. 303.

As the river falls in the winter months, its level will be reduced below that of the water-table of the flood plain so that this water will find its way back into the river in greater or less quantity according to the porosity of the stratum. Even in Nubia this takes place to some extent and near Serra about 15 hilometres north of Wadi Halfa on the west bank water can be seen at low stage trickling over the surface of a rock into the river.

In Egypt not many observations have been made on this point but during the flood of 1905 Mr. Naus[1] observed the level at Nag Hamadi of four open wells (saqias from which the wheel and pots had been removed) from June to October, and the results are shown on Plate XLI.

There is another source of water supply in this part which, though it does not affect the regiment of the river, is of considerable practical importance and merits more careful investigations than it has yet received. The eastern desert has already been described as being drained towards the Nile by numerous wadies, down which at considerable intervals the water from occasional rain storms pours; in the more northern part of this desert rain is more frequent and each winter several heavy rains occur. These furnish a perennial supply of water in the larger wadies, in the lower reaches of which there exist wells of 4 to 5 metres in depth sunk by the Arabs in the gravel; in these a small depth of water is maintained constantly as it flows through the gravel on the rocky bed of the valley until it reaches the Nile Valley where it sinks into the coarsely sandy beds which pass under the modern alluvial deposit of the Nile mud. Wells of moderate depth 50 to 60 metres have of late years been bored extensively into these sands for purposes of water supply with satisfactory results, but whether they draw a part of their supply from the Nile itself where it has cut its bed down into them is still uncertain.

The Chemistry of the Nile Silt and Nile Water.[2]—A considerable amount of chemical work has been done from time to time on the composition of both Nile silt and Nile water. The first published analysis that can be traced was a determination of the composition of the silt made in 1812 by Regnault.[3] Sometime between

[1] The results have been kindly communicated by Hon. A. Davey Director of the Company to whom I am indebted for permission to publish them.

[2] By Mr. A. Lucas, F. I. C. Superintendent of the Survey Department Laboratory.

[3] "Description de l'Égypte," Tome XX, Paris 1824.

1812 and 1841 a sample of silt was examined by Professor John;[1] additional work was done by Lassaigne in 1844;[2] by Lajouchère in 1850;[2] by Payen and Poinset in 1850;[2] and by Moustapha Magdaly in 1849-1850.[3] In 1851 a series of twelve samples of Nile silt and Nile deposit were analysed in detail for Horner by Johnson and Brazier under the superintendence of Hofmann.[4] In 1869 Houzeau[5] examined samples of silt; in 1872 Payen, Champion and Gastinel[6] analysed both the silt and water; in 1874-5 the first systematic study of the Nile water was made by Letheby who made complete monthly analyses extending over twelve months of both the water and the mineral matter in solution;[7] a few analyses of Nile water were made in the same years by Wanklyn;[8] in 1877 various odd samples of water from both the Blue and White Nile were examined but the name of the analyst is not stated;[9] in 1880 Tidy published analyses of the Nile water extending over twelve months but the year in which the samples were taken is not given;[10] in 1885 Judd carried out a detailed investigation of the microscopical characters of the Nile deposit;[11] in 1887 Mathey examined monthly samples of the water;[12] in 1888-9 one sample of water a fornight was analysed by Pollard;[13] in 1890 Schlœsing examined a sample of the silt;[14] and in the same year samples were also analysed by Muntz[15] and for the natural history museum at Paris.[16] In 1891 Droop Richmond[13] made a more detailed study of the river and analysed samples of the water taken from various places between Wadi Halfa and the sea. In ~~1861~~ Gabriel Bahri determined the chlorine in various samples of Nile water taken at different times of the year.[17] In 1899

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1 "Reisen in Europa, Asien und Afrika." J. Russeger, Stuttgart 1841.

2 Report on the Deposits of the Nile Delta. Judd. Proc. Royal Society No. 240, 1886, and Vol. 61.

3 "Mémoires de l'Institut Egyptien," Tome I, Paris 1862.

4 Phil. Trans. 1855, Part I, p. 105.

5 "Comptes Rendues," N° 10 (8 mars 1869).

6 Egyptian Irrigation. Willcocks, 2nd Edition, 1899 and also "Les Irrigations en Egypte.' Barois, Paris 1904.

7 The River Nile. Baker, Proc. Inst. C. E., Vol. LX, June, 1880.

8 Water Analysis. Wanklyn and Chapman, London 1889.

9 Quoted in "Le Nil, le Soudan, l'Égypte." Chélu Bey, Paris, 1891.

10 Dr. Meymott Tidy, Jour. Chem. Society, Vol. XXXVII. 1880, Trans., p. 268.

11 Proc. Royal Society, No. 240, 1886, and Vol. 61.

12 "Annales de la science agronomique," tome II., p. 340.

13 Contributions to the Chemistry of River Water. H. Droop Richmond.

14 Bull. Inst. Egypt., 1890.

15 Muntz, "Rapport à l'Académie des Sciences de Paris," quoted by Sickenberger in "La Configuration géologique des environs du Caire." Le Caire 1890.

16 "Muséum d'histoire naturelle de Paris," quoted by Ventre Bey in "Sol Egyptien et Engrais," Bulletin Institut Egyptien. N° 10 1889.

17 Gabriel Bahri. Paper read at meeting of Institut Egyptien, Jan. 1895.

Mackenzie[1] published the results of a considerable amount of work dealing with the composition of the Nile silt and the proportion in which it occurs in the river at different periods of the year, and he has in preparation further work on the same lines. In 1902 one sample of water from the Bahr el Gebel, Bahr el Zaraf and Sobat respectively were analysed in the Survey Department Laboratory.

In October 1904 a regular and systematic weekly examination of samples of the river water was commenced by the Survey Department Laboratory in connection with the control of certain sand filters at Giza.[2]

A considerable amount of the chemical work done in the past in connection with the Nile consisted in the examination of single samples of either the water or the silt, and the results obtained are comparatively useless on account of the great seasonal variations in the state of the river. The value of much of the work too is largely discounted by the fact that very frequently no details are given of how the sample was taken, the place from which it was taken or the manner in which it was examined. No work whatever appears to have been done on either the nature or amount of the gases dissolved in the river water.

A brief summary and criticism will now be given of the most important of the results obtained up to the present by the various investigators already alluded to.

The chemical aspect of the Nile may be conveniently considered under the following heads, namely :—

(1) The nature of the matter in suspension.

(2) The nature of the matter in solution.

Matter in suspension.—None of the results of the various published analyses can be considered as entirely satisfactory or as final. This is more particularly the case with all those dating before Letheby's work in 1874-5. In no instance is the nature of the "insoluble matter" stated ; in many cases the oxide of iron and alumina have been grouped together and not determined separately ; the carbon dioxide and moisture are frequently both omitted, while the organic matter and combined water are generally determined by "difference" or deduced from the percentage loss of weight of the sample on ignition.

The first attempt to determine the actual nature of the Nile silt apart from its ultimate chemical composition was made by Judd.

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[1] The Manurial Value of Nile Mud. Mackenzie. Jour. Khed. Agric. Soc., Cairo 1899 ; also Manures in Egypt and Soil Exhaustion. Mackenzie and Foaden. Jour. Khed. Agric. Soc., Cairo 1899.

[2] The results of most of this work will shortly be published by the Survey Department.

who referring to some samples of Nile deposit from Zagazig, says[1] that the specimens consisted of sand and mud mixed with varying quantities of organic matter, the sand containing felspar and other complex silicates in a nearly unaltered condition, while the mud was formed of "particles of the chemically unaltered minerals reduced to the finest dust by purely mechanical agencies," and kaolin appeared "to be almost altogether absent." If this is true of the Nile deposit it must be equally true of the silt in the river from which the deposit is derived, and one therefore naturally turns to the published analyses of the silt expecting to find the same facts clearly shown, but although many analyses have been made from time to time, yet as Judd points out, in none of these analyses has the combined water been determined separately, and in none of them has any attempt been made to distinguish the alumina existing as hydrated silicate (kaolin) from that present in other combinations; in fact in most of the analyses as already stated the alumina has not even been determined separately from the oxide of iron. The very important fact therefore of the percentage of kaolin present in the Nile silt, or even whether it is present at all has been left undetermined.

The following analyses may be quoted. These are not given in full but only so far as they bear on the matter under consideration. The carbon dioxide is Nos. 2, 3, and 4 has been calculated from the calcium and magnesium carbonates given in the original analyses.

Ingredient	(1)	(2)	(3)	(4)	(5)
	%	%	%	%	%
Insoluble matter and Silica ..	48·07	49·38	53·04	53·00	50·37
Alumina	19·08	13·60	8·76	14·57	21·90
Carbon Dioxide	1·47	4·78	1·84	0·94	1·66
Moisture	5·98	..	..	..	11·52
Water	..	12·10	..	..	
Organic Matter, etc...	8·43	4·88	9·03	2·84	
Undetermined and loss	0·59	..	..	10·58	0·11

In the absence of direct evidence it was thought that possibly the indirect indications might be helpful, and so the whole of the alumina

[1] Report on the Deposits of the Nile Delta. Proc. Roy. Soc. No. 240, 1886 and Vol. 61.

(1) Mackenzie. Journal Khedivial Agricultural Society, Vol. 1, p. 102.

(2) Sickenberger "La configuration Géologique des Environs du Caire." Le Caire, 1890.

(3) Brazier under superintendence of Hofmann. Phil. Trans. Royal Society 1855, Part. I., p. 105.

(4) Muntz. "Rapport à l'Academie des Sciences de Paris," quoted by Sickenberger in "La configuration Géologique des Environs du Caire." Le Caire 1890.

(5) "Muséum d'histoire naturelle à Paris." Quoted by Ventre Bey in "Sol Egyptian et Engrais," "Bulletin Institut Egyptien," No. 10, 1889.

present in the above analyses has been calculated to kaolin with the following results

Ingredient	1	2	3	4	5
	%	%	%	%	%
Kaolin	48·35	34·46	22·20	36·92	55·50
Containing Combined Water ..	6·72	4·79	3·08	5·13	7·71

The various percentages of combined water thus obtained are in every case less than the figures shown for organic matter, organic matter and undetermined, or water, organic matter, and undetermined. as the case may be, and since these several ingredients in the analyses are probably simply the "loss on ignition" less carbon dioxide, it follows that in no instance can it be proved from existing analytical data that kaolin is not present.

During the whole of that period of the year when there is a fair amount of sediment in the river it is found to be almost impossible to produce by sedimentation and filtration a water entirely free from opalescence, and it is only by the use of some coagulant, such as alum that a bright and clear filtrate can be obtained. Some of the suspended matter in the river is therefore in an extremely fine state of division, and it is probable that the greater part of this very finely divided matter is never deposited at all, either in the river channel or on the banks, and hence the absence of kaolin from Nile deposit would be no proof that this ingredient does not occur in the river. Further, no deposit from any one locality can be considered as necessarily representative of the general nature of the river silt. Writing on this question Regnault says: "Il faut observer que les quantités de silice et d'aluminie varient selon les lieux où l'on prend le limon; sur les bords du Nil le limon tient beaucoup de sable; et lorsqu'il est porté par les eaux de l'inondation dans les terres éloignées il perd en chemin une quantité de sable proportionelle à sa distance du fleuve; de manière que lorsque cette distance est très considérable on trouve l'argile presque pur." [1]

Clay soils occur very extensively in Egypt, but whether this clay is hydrated silicate of alumina or not cannot be stated; it has all the physical characteristics of true clay and is very sticky and plastic when wet and cracks and becomes hard when dry, while it has been used

[1] "Description de l'Egypte." tome XX. Paris 1824.

for brickmaking from the earliest times of which there are any records. It is now generally recognized however that the so-called "clay" properties depend upon the fineness rather than the nature of the particles.[1]

According to some mechanical analyses made by Means[2] the amount of clay (*i.e.* soil particles having a diameter from 0·005 to 0·0001 mm) found in some Egyptian soils was in one or two cases as much as 75 per cent, and in only 6 samples out of 21 was it less than 40 per cent.

The Nile mud was at one time the great fertilizer of Egypt and for thousands of years an integral part of Egyptian agriculture was to obtain on the land each year a deposit of the sediment from the red flood water, but with the advent of perennial irrigation this sediment is being less deposited on the land but passes away into the sea.

The valuable fertilizing ingredients in the mud are phosphoric acid potash, and nitrogen, the latter being contained in the organic matter present. The following analyses show the proportion in which these several constituents occur:-

Ingredients	A	B	C	D
Phosphoric Acid..	0·21	0·32	1·78	0·57
Potash	0·68	0·98	1·82	1·06
Organic Matter	8·00	8·43	15·02	10·37

"Nile mud supplies sufficient quantities of phosphoric acid and potash for the growth of fair crops of cotton, wheat, barley, maize, beans and potatoes but does not do so for sugar cane, berseem and berseem hagazi (alfalfa)."[3]

"Nile mud does not supply a sufficient amount of nitrogen for the use of nitrogen consuming crops."[4]

The percentage of nitrogen in the suspended matter varies considerably at different times of the year, being highest from May to August and

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[1] The Soil A. D. Hall, London 1903.

[2] Reclamation of Alkali land in Egypt, T. H. Means U. S. Department of Agriculture, Washington 1903.

A and B. Mackenzie. Jour. Khed. Agric. Soc., Vol. 1, page 102.

C and D. Letheby. The River Nile, Baker Mins. Proceeds. Inst. C.E. Vol. LX June 1880.

[3] Dr. W.C. Mackenzie. The Manurial value of Nile Mud. Jour Khed. Agric. Soc., Cairo 1899, p. 102.

[4] Manures in Egypt and Soil Exhaustion, Mackenzie and Foaden J.K.A.S. 1890, p. 137.

lowest from September to December. The following tabular statement will make this clear.

Month	Nitrogen per cent in total suspended matter[1]	Month	Nitrogen per cent in total suspended matter[1]
January..	0·0620	July	0·6120
February.	0·0638	August	0·6186
March	0·0842	September.	0·0161
April	0·1056	October	0·0232
May	0·6030	November	0·0370
June.	0·7030	December	0·0364

From these figures Dr. Mackenzie argues that "as far as nitrogen is concerned. . . . . . . the suspended matter of the red water is of less value than at any other period." [1]

Taking equal weights of the sediment at the different seasons this is doubtless true, but the amount of silt itself is very much greater at the time of red water, and hence the total amount of nitrogen is far higher during the flood than at any other period.

This fact is well illustrated by the results obtained in the Survey Department Laboratory in the examination of the unfiltered river water. As soon as the flood arrives the amount of albuminoid ammonia, which is a measure of the nitrogenous organic matter, at once notably increases and this increase is due to suspended and not to dissolved material.

The following are the results obtained :—

MILLIGRAMS PER LITRE (PARTS PER MILLION), 1905. [2]

Month	Albuminoid ammonia	Month	Albuminoid ammonia
January	0·385	July..	0·850
February	0·353	August	0·888
March	0·298	September	1·670
April.	0·281	October	0·982
May..	0·391	November	0·521
June	0·590	December.	0·423

But apart from the nitrogen contents the organic matter itself is not without value from an agricultural point of view, especially in modifying the physical characters of the soil.

[1] Manures in Egypt and Soil Exhaustion. by Mackenzie and Foaden J.K.A.S. 1370, p. 137.
[2] Monthly means from weekly samples.

In addition to the constituents usually recorded in all analyses of Nile silt Sickenberger states that he found traces of gold, copper, and iodine.[1]

The amount of organic matter as measured by the "loss on ignition" found in the samples of silt from Sarras already alluded to varied from 2·2 milligrams per litre in June to 123·7 milligrams per litre in August.

In connection with the suspended matter in the river the bacteria should be mentioned since these too are in suspension. At present very little is known concerning the bacterial flora of the Nile; weekly counts however on agar at 37° C. (after 48 hours) have been made in the Survey Department Laboratory during 1905 and the number of bacteria found has varied from 560 per c.c. in February to 28,260 per c.c. at the beginning of July.

Matter in Solution.—The soluble matter, like the suspended matter, varies very much at different times of the year, being highest when the river is at its lowest ebb, and gradually decreasing as the river rises, until the minimum is reached when the Nile is at its highest flood level, after which the proportion gradually rises again as the river falls.

The proportion of soluble matter not only varies from month to month, but also from year to year.

The following summary may be given of some of the results obtained in the Survey Department Laboratory in 1905.

MILLIGRAMS PER LITRE. (PARTS PER MILLION).
(*Weekly samples.*)

Date	Total soluble Matter	Chlorine	Nitric Acid as Nitrogen	Albuminoid Ammonia	Oxygen absorbed (Kübel)
1905					
January	170	6·7	trace	0·155	1·63
February	193	9·6	nil	0·130	1·88
March	207	14·7	nil	0·127	2·47
April	230	20·1	nil	0·118	1·51
May	240	24·3	trace	0·128	1·47
June..	230	23·7	nil	0·148	1·51
July	216	20·5	nil	0·225	2·04
August	180	12·2	0·37	0·207	1·95
September	140	3·6	0·52	0·097	1·13
October	132	3·7	0·14	0·113	1·23
November	146	5·0	0·08	0·081	0·95
December	150	6·8	trace	0·115	1·42
Maximum	260	26·0	0.70	0·270	3·00
Minimum	125	2·5	nil	0·065	0·75

[1] "La configuration géologique des environs du Caire," Cairo 1890.

The amount of organic matter in solution is only very small: as measured by the albuminoid ammonia and the oxygen absorbed it was highest during 1905 in July and lowest in November; the amount of nitric acid is also very slight, and in 1905 was highest in September. From an agricultural point of view none of the soluble constituents are present in sufficient quantity to appreciably affect the crops.

As already mentioned a complete mineral analysis of the soluble matter in the river was made by Letheby on each of the monthly samples of water examined by him.

The following results may be quoted.

MILLIGRAMS PER LITRE (PARTS PER MILLION).

Constituents	1	2	Constituents	1	2
Lime..	44.2	51.8	Phosphoric Acid.. ..	trace	trace
Magnesia..	10.3	10.3	Nitric acid	trace	trace
Soda..	5.9	13.0	Silica, etc	11.3	6.7
Potash	15.0	4.0	Organic matter	11.9	31.3
Chlorine	6.3	17.4	Carbonic acid and loss.	42.8	40.9
Sulphuric Acid	18.4	29.3			

The minimum and maximum figures obtained by Maymott Tidy in the partial mineral analyses made monthly by him already alluded to are as follows:—

MILLIGRAMS PER LITRE (PARTS PER MILLION).

Constituents	Minimum	Maximum
Total solid matter.	136·0	204·0
Nitrogen as Nitrates	trace	trace
Lime	29·3	62·1
Magnesia.	4·6	15·5
Sulphuric anhydride	17·0	26·3
Chlorine	2·1	19·9

Reasoning from Tidy's results Judd says "But it is startling to find that the water of the Nile instead of containing a much larger proportion of saline matter than other rivers as we might anticipate from the enormous evaporation constantly going on from its surface in reality

1 Letheby, Sample taken August 12, 1874 at high Nile. The River Nile. Baker Mins. Proc. Inst. C.E. Vol. LX, June 1880.

2 Letheby. Sample taken May 13, 1875 at low Nile. loc. cit.

contains far less dissolved matter than any of the other rivers here compared with it"[1] (*i. e.* Thames, Lea, Severn and Shannon).

"Hence we are led by an examination of the composition of Nile water to the same conclusion as was reached by the study of the microscopical characters of the muds and sands of the Delta, that while in the rainy districts of the temperate zone the disintegration of rocks is mainly effected by chemical agencies, in the desert areas of the tropics the same work is almost exclusively effected by mechanical forces."

But although there is with the Nile much greater evaporation than in the case of European rivers, and although, there is also an almost entire absence of rain to make good the loss occasioned by this evaporation, yet the smaller amount of dissolved matter may be accounted for in other ways, namely, first by the fact that there is no discharge into the Nile of large volumes of sewage laden with soluble salts such as is the case with European rivers, secondly, the absence of rain means not only the absence of storm water carrying with it the surface washings from the land, but also a smaller amount of water that has been in contact with the soil for any length of time, and which holding in solution the various salts it has dissolved finally finds its way into the river.

Judd's conclusions therefore that a small mineral content in the river necessarily means a limited amount of chemical rock-disintegration, and hence an almost complete absence of kaolin are by no means certain.

Kaolin may be almost altogether absent from the Nile sediment, but this is not proved by its absence from the Zagazig boring samples, nor by the relatively small amount of soluble matter in the Nile. The Zagazig samples may not be at all typical either of the silt in the river, or the sediment deposited elsewhere, and the small amount of soluble matter in the Nile water may be due not to any lack of chemical decomposition of rocks, but to the fact that there is no rain either to carry the decomposed material into the river or to wash out of the land the inorganic salts resulting from animal and vegetable life, and also that in Egypt there no large cities pouring immense quantities of sewage into the river.

On a comparison of Tidy's results with those of Letheby for 1874-5 the two sets of figures are found to be very similar, the total matter in solution for exampla each month being identical. The following table gives the maxima and minima of various results showing the great variation in both the nature and amount of the soluble matter in the

[1] Loc. cit.

Nile, not only in different years, but also at different seasons of the same year.

MILLIGRAMS PER LITRE — PARTS PER MILLION.

Year	Analyst	Total Soluble Matter		Chlorine	
		Min.	Max.	Min.	Max.
1874-5	Letheby	136	204	2·1	17·4
..	Tidy	136	204	2·1	19·9
1888-9	Pollard	123	276	2·7	35·7
1905	Survey Department	125	255	2·5	26·0

In connection with the analyses made by Letheby, Wanklyn and Tidy it should not be forgotten that these samples were all examined in England and hence had been kept for a considerable time before analysis, and as organic matter undergoes change, being progressively oxidized to ammonia, nitrite and nitrate, all results having reference to substances of organic origin are valueless and must be disregarded.

No reference to the occurrence of iron, alumina, or manganese can be found in the published analyses of Nile water; these three substances however are all present.[1]

Although a good deal of useful work has been done on the chemistry of the Nile, yet in view of the enormous scientific interest and practical importance of the river the results obtained are comparatively small, and many problems yet remain to be solved.

Summary.—The Nile between Aswan and Cairo follows a depression in which it has gradually deposited a considerable thickness of alluvial mud, and now it meanders on the flood-plain which it has formed. In earlier times side channels followed the lower margins of the valleys, and lagoons and swamps existed in the same part of the valley, but now owing to controlled irrigation such parts have been reclaimed and former water channels such as the Sohagia Canal, and the Bahr Yusef are to-day supply-canals which irrigate the marginal portions of the valley. For the past fifty centuries at least the Nile has been depositing in this reach, and the average rise of the bed due to this is about 0·10 metre per century, so that some 5 metres of alluvial mud have been laid down in historical times. Before that it is not yet so clear; higher deposits of Nile mud seem to belong to an

[1] The Blackened Rocks of the Nile Cataracts and of the Egyptian Desert. A. Lucas. Cairo 1903.

older and a higher flood plain which has been cut down into by the river as the result of some change of condition which has not yet been traced. The needs of agriculture, and the requirements of a dense population have produced a strict control of the river so that the water of the low stage supply may be used as economically as possible, and the turbid water of the flood spread as widely as possible in order to deposit its sediment on the cultivated lands. The river therefore is more of the nature of a great supply canal than a stream free to meander through its flood-plain. Similar control of the water and consequent reclamation of the land have diminished the lake which once occupied the depression of the Fayum, until now a small and rapidly shrinking lake alone remains.

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higher land in the neighbourhood of the river arms with lakes, lagoons or in a later stage marshes which occupy the lower-lying area between them. Finally these are filled up by deposition in the part of the delta near its apex and the marshes and flooded region are entered somewhat lower downstream. As the delta extends seawards the length of the river is increased and the grade of this portion has to re-adjust itself in order to provide the requisite slope to carry the suspended material to the river mouth, so that the surface of the delta is raised and its apex moves up-stream. Having now but two main channels which reach the sea the Nile is only extending its delta at these two points, viz., the Rosetta and Damietta mouths, but even here the advance is not rapid since the sediment brought down by the river in flood is to a great extent distributed by the currents produced by the steady northerly wind of the summer months. In the lakes sedimentation is taking place but the volume of silt bearing water received by them small compared with that carried by the main arms.

In the early times of ancient Egyptian history the delta was largely an area of marsh; the main arms, of which seven are recorded by Greek authors, divided into numerous branches, and followed meandering courses to the sea. In the flood season all these overflowed their banks, depositing their load of silt to raise the delta and fill the low-lying depressions with water so that they remained as water-logged marshes throughout the year; the river arms and smaller water channels, until they were trained and embanked in much later times, eroded their banks, and cut across their bends to leave deep crescent-shaped lakes where their channels had formerly been, as is to be seen in all deltas of rivers which periodically rise in flood. At this period the larger settlements must have been in the neighbourhood of the larger branches where sufficient high ground had been formed to provide areas of cultivable land, until the marshes became silted up, forming a plain suitable for cultivation.

Geology.—Within the area of the delta no rock appears except the limestone of Alexandria which forms a low ridge in this part of the coast and extends westwards as a low line of hills parallel to the shore. East of Abukir it does not appear and the rest of the delta is formed of the alluvial mud and fine sand brought down by the Nile, on which near the sea coast are sand dunes formed by the northerly winds.

The alluvial mud and sand of the delta rests upon a thick deposit of yellow quartz sands of varying coarseness which include also layers of gravel, and also lenticular masses of stiff clay. These are generally considered to have been deposited at a time when the sea extended for a


Port Said
El Menzaleh
San el Hagar
Baqar
Wadi Tumilat
Canal
Timsah L.
10
20
30 Miles

considerable distance up the valley, before the Nile existed in its present form. Though a boring has been carried down to 104 metres at Zagazig by the Royal Society no rock was met with, nor was any proved in a boring of 163 metres made by the Abukir Company on their lands to the east of Alexandria. The Delta then has been deposited on a thick series of fluvio-marine sands, clays, and gravels which were deposited in the fault valley, in which is now the cultivated land of Egypt.

The thickness of the Nile mud varies considerably from point to point, partly doubtless from the uneven surface on which it is deposited, and partly also from the difficulty in some cases of determining at what point the lower sands replace the Nile mud in the section. The following table gives the thickness of it as found in recent well borings:—

PLACE	Thickness of Nile mud	Depth bored to	PLACE	Thickness of Nile mud	Depth bored to
	metres	metres		metres	metres
Shamarka (Kafr el Sheikh).	17	42	Beni-Suef[2]	10	204
Simbellawein.. ..	5	9	Beni-Suef (Hospital)	11	..
Zagazig[1]	?	104	Tahta.	14	29
Zagazig	13	35	Sohag.	17	40
Qaliub	12·5	52	Tanta	8	..
Benha	17	37	Mehallet Roh.. ..	9	..
Cairo (Rod el Farag)	17	60	Samanud	12	..
Giza	20	38	Kasr el Nil	15	..
Gezira (Cairo). ..	8	36	Helwan, river bank.	19	44
			Luxor	15	30

Climate.—The climatic conditions of the delta represent two types since in winter those of the Mediterranean province extend over the whole of it, while in summer the Saharan type predominates except in a comparatively narrow belt near the coast. Observations are not numerous and Alexandria and Port-Said on the north, and Cairo on the south furnish the only series of any length. The passage from the moister conditions of the cultivated area to the aridity of the desert is shown by Ismailia and Suez on the east and a short series from the Wadi Natrun on the west.

MEAN TEMPERATURE CENTIGRADE.

PLACE	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	YEAR
Alexandria .	14·2	15·5	17·0	19·2	21·9	24·3	26·2	26·9	25·9	24·1	19·9	16·2	20·9
Port-Said[3]..	14·0	15·3	16·9	19·1	22·0	24·7	27·0	27·6	26·5	24·9	20·3	16·1	21·2
Ismailia[3] ..	13·2	15·2	17·5	20·8	23·9	26·5	28·5	28·3	26·1	23·8	18·7	15·1	21·5
Suez[3].. ..	13·6	15·5	18·0	21·7	25·3	27·6	29·4	29·2	27·1	24·8	19·1	15·4	22·2
Cairo	12·3	13·8	16·9	21·2	24·8	27·9	28·6	28·1	25·6	23·6	18·9	14·8	21·4

[1] Boring made by Royal Society.

[2] Sands ended at 32 m. rest in limestone.

[3] $\frac{\text{Maximum}+\text{minimum}}{2}$

Mean maximum temperature centigrade.

Place	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Alexandria .	18·0	19·4	21·1	23·6	26·2	28·0	29·6	30·3	29·5	27·7	23·7	20·1	24·8
Port-Said ..	18·4	19·9	21·5	23·9	26·7	29·1	31·8	32·1	30·8	29·2	24·6	20·4	25·6
Ismailia ..	18·4	21·0	23·6	27·7	31·2	33·8	35·5	34·9	32·3	30·1	24·5	20·5	27·8
Suez	19·1	21·5	24·3	28·8	33·0	35·3	36·8	36·1	33·8	31·4	25·0	21·1	28·8
Cairo	18·3	21·1	24·2	28·6	32·6	35·1	36·1	34·9	32·2	30·1	24·3	20·2	28·2

Mean minimum temperature centigrade.

Place	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Alexandria .	10·4	11·6	12·8	14·9	17·6	20·6	22·9	23·5	22·3	20·5	16·1	12·3	17·1
Port-Said ..	9·7	10·7	12·2	14·3	17·4	20.3	22·2	23·2	22·2	20·7	16·1	11·8	16·6
Ismailia ..	7·9	9·4	11·3	13·9	16·5	19·1	21·5	21·7	19·8	17·6	13·0	9·7	15·1
Suez	8·1	9·5	11·7	14·6	17·6	20·0	22·0	22·2	20·2	18·2	13·2	9·8	15·6
Cairo	6·9	8·2	9·9	12·8	15·9	18·5	20·8	20·8	18·9	17·1	12·3	8·8	14·4

Mean maximum extreme centigrade.

Place	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Alexandria .	21·7	25·9	31·1	34·3	36·6	36·0	32·1	32·0	33·1	32·4	28·1	25·0	30·7
Port-Said ..	21·6	26·0	30·8	32·1	34·6	35·0	35·5	34·9	33·0	32·5	28·8	24·5	30·8
Ismailia ..	22·9	27·3	32·3	36·8	38·8	40·5	39·2	38·4	36·6	34·5	29·4	25·4	33·5
Suez	22·9	26·6	31·7	35·7	39·8	42·0	40·3	39·8	38·2	35·7	30·1	25·1	34·0
Cairo	22·6	28·2	33·8	37·6	40·4	41·6	39·7	40·0	36·9	35·2	29·1	25·3	34·2

Range.

Place	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Alexandria .	7·6	7·8	8·3	8·7	8·6	7·4	6·7	6·8	7·2	7·2	7·6	7·8	7·6
Port-Said ..	8·7	9·2	9·3	9·6	9·3	8·8	9·6	8·9	8·6	8·5	8·5	8·6	9·0
Ismailia ..	10·5	11·6	12·3	13·8	14·7	14·7	14·0	13·2	12·5	12·5	11·5	10·8	12·7
Suez	11·0	12·0	12·6	14·2	15·4	15·3	14·8	13·9	13·6	13·2	11·8	11·3	13·2
Cairo	11·4	12·9	14·3	15·8	16·7	16·6	15·3	14·1	13·3	13·0	12·0	11·4	13·9

Mean extreme minimum temperature centigrade.

Place	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Alexandria .	6·8	8·2	9·3	12·0	14·5	17·8	21·0	21·2	19·1	16·6	12·0	7·7	13·8
Port-Said ..	6·3	7·9	8·5	11·1	13·2	16·7	19·3	20·2	19·4	16·7	11·0	8·1	13·2
Ismailia ..	4·4	6·3	7·0	9·8	12·5	16·3	19·6	19·7	16·9	14·2	9·0	5·5	11·8
Suez	4·3	6·0	7·3	10·6	13·4	17·2	19·2	20·0	17·3	14·2	8·8	5·4	12·0
Cairo	2·5	4·0	5·6	8·8	11·7	16·0	18·3	18·2	15·8	13·6	8·5	4·5	10·6

RELATIVE HUMIDITY PER CENT (8 or 9 a.m.).

PLACE	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	YEAR
Alexandria .	64	62	61	60	60	64	67	64	63	64	61	66	63
Port-Said ..	79	78	74	72	71	72	75	74	74	76	75	80	75
Ismailia ..	84	80	75	70	71	74	77	80	80	82	83	84	78
Suez	76	74	70	65	64	66	70	74	75	77	78	76	72
Cairo	72	70	61	54	50	53	61	67	68	72	72	74	64

RELATIVE HUMIDITY PER CENT (2 or 3 p.m.).

PLACE	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	YEAR
Alexandria .	54	52	51	53	56	60	61	58	56	58	55	58	56
Port-Said ..	65	62	59	59	60	62	64	63	62	64	63	66	62
Ismailia ..	49	43	38	32	30	30	32	34	40	42	47	51	39
Suez	40	35	32	27	25	24	27	28	30	34	38	41	32
Cairo	48	43	34	30	27	27	29	32	39	41	44	49	36

VAPOUR TENSION MILLIMETRES (8 or 9 a.m.).

PLACE	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	YEAR
Alexandria .	7·4	7·6	8·3	9·8	12·0	15·3	17·7	17·4	16·0	14·7	11·2	8·7	12·2
Cairo	7·0	7·5	8·2	9·1	10·7	13·2	15·9	16·8	15·8	14·6	10·7	8·5	11·5

VAPOUR TENSION MILLIMETRES (2 or 3 p.m.).

PLACE	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	YEAR
Alexandria .	7·5	7·6	8·3	9·9	12·4	15·6	18·1	17·7	16·1	14·6	10·8	8·8	12·3
Cairo	7·0	6·9	7·1	7·6	8·8	10·4	11·5	12·7	13·1	12·2	9·6	8·1	9·5

The rainfall is light and is not of much importance in most parts except that near Alexandria the winter rainfall is counted upon to some extent to supply a certain amount of water while the supply canals are temporarily closed for cleaning. To the west of Alexandria the rainfall is heavier and a valuable crop of barley is cultivated by the Arabs on the belt of country lying near the shore of the Mediterranean, and the ruins of numerous cisterns, dams and other ancient buildings show how extensively cultivation was formerly carried on by artificially storing the winter rainfall.

The following table shows the decrease of the amount of rainfall from west to east:—

Place	No. of years	Mean yearly rainfall	Place	No. of years	Mean yearly rainfall
		mm.			mm.
Algiers	54	683	Tripoli	8	354
Philippeville	20	807	Bengazi	5	354
Tunis.	5	487	Alexandria	38	220
Gabes	6	187	Port-Said	20	84

The quantity of rain which has been recorded in each month at Alexandria, Port-Said, Ismailia and Suez is given here.

MONTHLY RAINFALL IN MILLIMETRES.

Alexandria [1]

Date	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1867.. ..	..	..	..	..	..	..	..	..	..	..	41	130	[171]
1868.. ..	27	96	25	6	0	0	0	0	4	11	40	96	305
1869.. ..	59	20	1	2	0	0	0	0	0	0	40	39	161
1870.. ..	27	3	28	10	0	0	0	0	0	1	0	11	80
1871.. ..	5	78	33	1	0	0	0	0	0	13	7	43	180
1872.. ..	64	35	82	4	0	0	0	0	0	0	27	101	313
1873.. ..	51	80	19	4	0	0	0	0	0	9	80	58	301
1874.. ..	67	23	51	0	1	0	0	0	0	7	15	19	183
1875.. ..	95	34	26	0	0	0	0	0	0	0	15	25	195
1876.. ..	41	10	21	3	1	0	0	0	0	76	112	11	275
1877.. ..	87	91	9	1	0	0	0	0	0	24	27	28	267
1878.. ..	22	30	32	0	0	0	0	0	0	0	24	15	123
1879.. ..	16	13	22	1	0	0	0	0	0	0	0	34	86
1880.. ..	50	28	17	3	0	0	0	0	4	1	27	140	270
1881.. ..	1	22	16	1	3	0	0	0	0	1	66	62	172
1882.. ..	85	70	5	22	1	0	0	0	..	..	..	..	[183]
1883.. ..	60	49	0	0	0	0	0	0	5	17	94	15	240
1884.. ..	183	48	0	0	1	0	0	0	2	7	28	34	303
1885.. ..	106	10	6	11	0	0	0	0	13	0	30	56	232
1886.. ..	1	21	6	0	1	0	0	0	25	0	0	38	92
1887.. ..	98	34	6	3	0	0	0	0	0	0	4	37	182
1888.. ..	68	46	0	3	13	0	0	0	0	1	51	99	281
1889.. ..	64	38	4	2	0	0	0	0	0	0	63	84	255
1890.. ..	70	3	7	4	0	0	0	0	0	0	90	60	234
1891.. ..	50	44	29	0	0	0	0	0	12	0	0	48	183
1892.. ..	59	8	14	0	0	0	0	0	0	8	99	26	214
1893.. ..	80	19	47	0	0	0	0	0	0	7	13	98	264
1894.. ..	48	9	34	0	4	0	0	0	0	0	96	26	217
1895.. ..	0	1	1	9	0	0	0	0	0	0	16	87	114
1896.. ..	52	24	11	1	0	0	0	0	0	0	47	33	~~816~~
Mean ..	56	34	19	3	1	0	0	0	2	7	40	54	216

[1] Piroma Met. Zeit., 1884, p. 34, and 1897, p. 377.

Alexandria (Kom el Nadura, alt. 113 metres).

Date	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1891.. ..	9	9	7	0	0	0	0	0	6	4	2	76	113
1892.. ..	51	11	13	2	2	0	0	0	0	11	85	23	198
1893.. ..	89	27	53	2	3	0	0	0	0	6	11	107	298
1894.. ..	52	17	40	0	6	0	0	0	0	0	102	30	247
1895.. ..	1	0	4	16	0	0	0	0	0	0	46	100	167
1896.. ..	69	45	19	2	0	0	0	0	1	1	41	27	205
1897.. ..	126	12	14	0	0	0	0	0	0	14	1	107	274
1898.. ..	57	46	1	0	0	0	0	0	0	0	60	144	308
1899.. ..	73	23	2	0	0	0	0	0	0	58	25	64	245
1900.. ..	14	33	16	0	2	0	0	0	0	0	10	125	200
1901.. ..	83	0	4	0	0	0	0	0	14	0	30	57	188
1902.. ..	104	8	4	6	1	0	0	0	0	5	36	92	256
1903.. ..	90	34	14	1	0	0	0	0	0	0	10	24	173
1904.. ..	63	13	0	2	0	0	0	1	0	3	65	50	197
1905.. ..	46	16	14	0	0	0	0	0	0	28	7	160	271
Mean ..	62	20	14	2	1	0	0	0	1	9	35	79	223

Port-Said.

Date	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1886.. ..	56	7	20	7	0	0	0	0	0	1	1	2	94
1887.. ..	22	19	2	0	0	0	0	0	0	0	13	6	62
1888.. ..	50	0	0	1	0	6	0	0	0	0	15	19	91
1889.. ..	8	11	3	0	0	0	0	0	1	0	1	3	27
1890.. ..	29	0	21	25	0	0	0	0	0	0	9	12	96
1891.. ..	24	14	4	1	0	0	0	0	0	0	3	61	107
1892.. ..	16	1	12	2	0	0	0	0	0	2	25	9	67
1893.. ..	16	2	40	10	2	0	0	0	0	21	3	89	183
1894.. ..	10	18	16	0	0	0	0	0	0	0	52	2	98
1895.. ..	4	3	2	20	0	0	0	0	0	0	9	11	49
1896.. ..	18	31	14	3	9	0	0	0	0	2	12	4	93
1897.. ..	16	7	13	0	2	0	0	0	0	0	28	64	130
1898.. ..	6	6	8	0	0	0	0	0	0	0	43	11	74
1899.. ..	5	4	0	0	0	0	0	0	0	2	3	15	29
1900.. ..	10	32	0	0	0	0	0	0	0	0	2	23	67
1901.. ..	34	0	0	0	1	0	0	0	0	0	17	38	90
1902.. ..	14	5	7	9	0	0	0	0	0	1	7	9	52
1903.. ..	29	12	10	0	0	0	0	0	2	0	2	2	57
1904.. ..	28	12	1	21	6	0	0	0	0	4	8	37	117
1905.. ..	24	2	22	0	0	0	0	0	0	3	0	45	96
Mean ..	21	9	10	5	1	0	0	0	0	2	13	23	84

Ismailia.

Date	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1886.. ..	16	3	5	2	4	0	0	0	0	0	2	11	43
1887.. ..	12	6	5	6	12	0	0	0	0	0	0	6	47
1888.. ..	17	16	0	14	19	0	0	0	0	1	5	11	83
1889.. ..	18	2	1	0	0	0	0	0	0	0	0	1	23
1890.. ..	28	4	20	6	0	0	0	0	0	0	1	14	73
1891.. ..	13	9	8	0	0	0	0	0	0	44	0	23	97
1892.. ..	3	0	0	0	0	0	0	0	0	0	8	2	13
1893.. ..	22	2	19	0	0	0	0	0	0	1	2	32	78
1894.. ..	3	14	2	0	1	0	0	0	0	0	13	3	35
1895.. ..	1	0	2	28	7	0	0	0	0	0	40	2	80
1896.. ..	7	4	6	1	3	0	0	0	0	0	0	3	24
1897.. ..	8	0	7	0	1	0	0	0	0	0	13	3	32
1898.. ..	3	1	2	0	0	0	0	0	0	0	10	10	26
1899.. ..	2	10	3	0	0	0	0	0	0	4	6	13	38
1900.. ..	9	26	0	0	0	0	0	0	0	0	0	36	71
1901.. ..	7	0	0	0	10	2	0	0	0	0	0	6	25
1902.. ..	6	4	6	0	0	0	0	0	0	0	4	0	20
1903.. ..	4	1	11	0	0	0	0	0	1	0	0	20	37
1904.. ..	20	12	0	4	0	0	0	0	0	0	2	15	53
Mean ..	10	6	5	3	3	0	0	0	0	3	6	11	47

Port-Taufik (Suez).

Date	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1886.. ..	..	..	..	..	..	..	..	..	..	..	..	8	[8]
1887.. ..	3	0	4	10	0	0	0	0	0	0	0	0	17
1888.. ..	0	4	9	4	1	0	0	0	0	0	0	0	18
1889.. ..	28	0	1	0	1	0	0	0	0	0	0	7	37
1890.. ..	15	3	6	2	0	0	0	0	0	0	0	2	28
1891.. ..	18	0	0	0	0	0	0	0	0	0	0	9	27
1892.. ..	0	0	0	0	1	0	0	0	0	0	0	0	1
1893.. ..	12	0	0	0	0	0	0	0	0	0	0	12	24
1894.. ..	0	8	1	0	0	0	0	0	0	0	4	0	13
1895.. ..	0	0	2	7	0	0	0	0	0	0	2	0	11
1896.. ..	4	1	6	0	3	0	0	0	0	0	0	0	14
1897.. ..	0	0	0	0	0	0	0	0	0	0	2	0	2
1898.. ..	5	0	10	0	0	0	0	0	0	0	3	6	24
1899.. ..	2	0	2	0	0	0	0	0	0	0	0	0	4
1900.. ..	0	18	1	0	0	0	0	0	0	0	0	9	28
1901.. ..	3	0	0	0	8	0	0	0	0	0	0	0	11
1902.. ..	8	11	1	0	0	0	0	0	0	3	2	0	25
1903.. ..	1	0	0	0	0	0	0	0	0	0	0	24	25
1904.. ..	17	14	0	7	0	0	0	0	0	0	0	10	48
1905.. ..	18	1	0	5	0	0	0	0	0	0	0	0	24
Mean ..	7	3	1	1	0	0	0	0	0	0	0	4	16

It has been persistently stated that the improved irrigation of recent years in Egypt and the consequent extension of cultivation has modified the climate, rendering it cooler in summer, colder in winter and increasing the humidity and rainfall. Accurate observations extend over too short a time to refute or establish this view, and the positions of the observing stations are not the most favourable for doing so, since Alexandria and Port-Said are on the coast, and Cairo is at the extreme apex of the delta and close to the desert. The principal change which has taken place in agriculture is the great development of summer cultivation before the arrival of the flood, which has been rendered possible by the repair of the Delta Barrage and by the construction of the Zifta and Assiut Barrages and the Aswan dam; we may therefore expect to find an increase in the humidity in the early summer months in the delta. Further up the river it is less likely to be noticeable as the winds blow from the deserts and have a comparatively narrow strip of irrigated land to pass over, while in both cases the immediate surroundings of the station will have undue influence. In examining the humidity it will be noticed that both the relative and absolute humidity begin to increase in June not only in the delta and the Nile valley but also in the desert, *e.g.* Kharga and Dakhla oases, Aswan and Wadi Halfa so that this is a seasonal effect and not due to agricultural development only.

MEAN RELATIVE HUMIDITY PER CENT.

MONTH	Alexandria [1]	Port-Said	Cairo	Assiut	Aswan	Wadi Halfa	Kharga	Dakhla
March	61	77	59	57	34	32	24	38
April	62	77	51	42	31	24	19	27
May	65	75	47	34	29	19	14	20
June	69	76	47	33	26	21	18	19
July	70	81	50	36	24	27	19	20
August	68	79	56	44	26	32	18	29
September	65	76	62	54	32	32	27	34
October	66	77	66	61	38	36	28	37

[1] Kom el Nadura.

MEAN (VAPOUR TENSION) IN MILLIMETRES.

MONTH	Alexandria t	Port-Said	Cairo	Assiut	Aswan	Wadi Halfa	Karga	Dakhla
March	8·2	10·7	7·8	7·0	5·9	5·9	4·2	6·9
April	9·6	12·1	8·7	7·7	7·6	6·2	4·6	6·4
May	12·2	13·9	9·9	7·9	9·6	6·5	5·0	6·5
June	15·4	16·6	11·9	8·8	9·7	7·6	6·0	7·3
July	17·7	..	13·6	10·7	8·4	9·6	7·1	7·5
August	17·4	..	14·6	11·5	8·4	11·1	6·7	11·0
September	15·9	..	14·2	12·6	10·0	10·2	8·1	11·2
October	14·6	..	13·2	12·4	10·5	9·9	8·1	10·7

The percentage frequency of winds at Alexandria according to their directions is given on the following table.

(1875-1896) OBSERVED BY M. PIRONA.

DIRECTION	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
N.	16	19	25	29	41	47	44	51	56	42	28	16
N.E.	6	8	14	16	14	9	1	2	9	23	18	11
E.	11	11	11	11	8	2	0	1	3	9	11	10
S.E.	8	7	6	7	3	1	0	0	1	3	4	8
S.	13	10	5	3	2	1	0	0	1	2	7	13
S.W.	14	10	6	2	1	1	1	0	1	2	5	14
W.	10	10	6	5	4	3	3	3	1	2	7	9
N.W.	17	23	25	24	25	34	50	41	25	13	16	14
Calm ..	5	2	2	3	2	2	1	2	3	4	4	5

Kom el Nadura (1891-1900).

DIRECTION	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
N.	8·2	11·8	14·8	24·7	25·2	36·4	26·6	30·2	44·1	36·6	30·5	10·3
N.E.	8·2	11·2	15·2	21·6	15·3	9·4	0·1	0·6	9·7	30·2	20·6	11·8
E.	4·8	4·1	4·1	5·2	4·7	0·7	..	..	1·4	1·4	4·1	7·2
S.E.	10·8	8·0	10·2	7·6	10·9	0·8	..	..	0·8	3·0	5·8	8·6
S.	5·4	3·9	2·5	0·4	0·1	..	..	..	0·4	1·0	1·5	5·2
S.W.	17·2	14·2	5·2	1·4	0·3	..	0·2	..	0·2	0·3	7·0	21·0
W.	19·0	20·8	11·3	9·4	7·7	4·2	6·9	1·8	2·6	4·3	7·5	15·6
N.W.	24·9	25·6	35·3	28·4	35·2	48·5	66·2	67·2	40·8	23·1	23·0	19·7
Calm ..	1·5	0·4	1·3	0·3	..	..	..	..	..	..	..	0·6

Hydrography.—The apex of the Delta is now at the Delta Barrage where the river bifurcates to form the Rosetta and Damietta branches, but it has been suggested that in earlier times it lay further to the south. The evidence on this point is somewhat contradictory but it seems probable that when the Tanitic and Pelusiac branches were important, the arm which supplied them was a large one and the point where it left the main stream, about 7 kilometres below Cairo, was sometimes described as the point of the Delta.

Slope of the Delta. [1]—The slope of the surface of the Delta and the river bed is given in the following table:—

Rosetta Branch.

Distance from Delta Barrage	Top of Bank	Flood level 1892	Ground level	Bed level	Flood slope
kilometres	metres	metres	metres	metres	1 inch
0	19·00	18·03	16·42	9·0	
20	18·01	16·75	15·02	7·8	12,700
90	17·06	15·10	13·00	6·0	
60	15·00	13·20	12·17	3·2	
80	13·48	12·25	10·31		12,800
100	12·74	10·20	8·61		
120	10·60	9·30	7·30		16,700
140	8·60	7·75	6·20	Below sea level	
160	7·42	6·40	4·12		
180	6·09	5·00	3·05		12,200
200	4·03	3·10	1·62		
220	2·77	1·50	0·48		10,000

The seven mouths of the Nile mentioned by the Greek authors are:—

NAME	ENTERED THE SEA	APPROXIMATE MODERN REPRESENTATIVE
I.—Canopic	Near Abukir	..
II.—Bolbitic	at Rosetta	Rosetta branch.
III.—Sebennytic.. ..	across lake Borollos ..	Bahr Tirah and Bahr el Shibin.
IV.—Phatnitic	at Damietta	Damietta branch.
V.—Mendesian	across lake Menzala ..	Bahr el Saghir.
IV.—Tanitic..	" " " ..	Bahr Moez.
IIV.—Pelusiac	by Pelusium east of Port Said	Bahr el Bagar.

[1] "Egyptian Irrigation," p. 43, and "The Nile in 1904," p. 54.

In all periods the principal towns will have been situated on the larger arms and if it were possible to locate their sites at different periods during past centuries, we might thereby trace to some extent the line of the water channels which supplied their inhabitants with water and served as the means of communication with other towns and districts.

But the position of these old river branches is only approximately known and much archæological work remains to be done in the identification of the towns of Egyptian, Greek and Roman times with the mounds which exist to-day and show where formerly populous centres stood.

Even then channels will have frequently been modified by branches developing more rapidly than the main stream, by cross-cuts being formed in high floods, by the natural or artificial retaining banks being breached and new channels scoured out by the escaping flood. Hogarth[1] indicates several ancient arms by means of sites determined near them. The present Bahr Tirah, with the Bahr Shibin for its upper reach, flowed apparently as the Athribitic Nile to reach the sea somewhat to the east of the present lake of Borollos, while the Bahr Nashart represents another which he considers as the lower portion of the Pharmuthiac Nile. But until enough evidence has been collected and has been critically examined it is waste labour to speculate on the position of the old channels in the central and southern part of the delta. At all times a network of rivers intersected it, and the annual flood with its load of suspended material must have frequently modified the relative importance of the different channels. The meandering course followed by many of the canals and drains of to-day point to their having originally been natural channels which have been utilized in the present irrigation system.

Considerable alteration in the lower reaches of these arms and their subsidiary channels was caused when the depression of the northern edge of the Delta took place, which occurred in post-Roman times, as is proved by rock-tombs on the shore at Alexandria which are now below sea-level. The question of this depression of the shore-line merits a detailed investigation and it would be of special importance to determine whether it reached its greatest amount in the west and was less in the eastern portion as seems probable. Besides the silting up of the ancient river arm, which deposited Nile alluvium in the Wadi Tumilat as far as Ismailia but which is unknown as a natural

[1] Journal of Hellenic Studies, vol. XXIV, 1904.

channel in historic times, there seems to have been a gradual dwindling of the eastern branches, and a development of the western ones, which it is tempting to connect with a rise of the land to the eastward; of this there is clear evidence in the Gulf of Suez but nearer the delta evidence is scarce. The precise levelling now in progress will furnish a means for determining after the lapse of some years whether any slow movement is now in progress and the question is a very important one since a very slight change of level would greatly alter the conditions of a large area of low-lying land near the lakes of Menzala and Borollos. The formation of numerous salines to the south of Ras Gharib in the Gulf of Suez appears to show that an upward movement is or very recently has been in progress there.

The conversion of swampy or flooded areas into cultivable land has proceeded of late years with great rapidity as a result of the immense amount of work which has been done in improving and developing the drainage of this part of Egypt. In the province of Beheira, which lies to the west of the Rosetta Branch of the Nile, it is possible to obtain a fairly accurate idea of the rate at which this transformation has progressed of late by comparing the maps which were prepared in 1892 on the scale of 1 : 10,000 with these of the revision which was made in 1903-4. In the earlier maps of 1892 a total area of 480 square kilometres was recorded as being either open sheets of water or permanent marshes, but on those of 1903 only 235 square kilometres fall under this category. The remainder has by drainage been converted into dry land, and already passed under cultivation to a greater or less extent.

In many places still narrow depressions of irregular shape show where once a branch of the river meandered through the low ground and often finally ended in a wide area of marsh which in the flood season was an expanse of open water.

CHAPTER X.

The Variation of the Nile Flood.

The most important as well as the most striking phenomenon of the Nile Basin is the annual flood which pours down from the Abyssinian tableland in July, August and September, supplying for some time a greater volume than can be utilized on the cultivated valley plains and carrying with it the silt which, wherever deposited, forms a soil of the greatest fertility. The river supply, which in May and June had dwindled in Egypt to that which was insufficient for the wants of the population of the Nile banks, now increases rapidly filling all canals and flooding much of the flood-plains on which the silt is deposited. We have seen that from the earliest times the height of the Nile flood was annually recorded as the most important event of the Egyptian year, and such it still continues to be, though in consequence of the increase of perennial irrigation at the expense of basin or flood irrigation, the volume of water in the river at the lower stages, January to July, has now a greatly increased importance.

In this chapter will be considered the variation in the volume of the Nile flood from year to year, in which no regular periodicity has been found though frequently asserted to exist.[1] Next the meteorological conditions which seem to exercise a controlling or modifying influence on the southerly monsun of East and Central Africa will be indicated,[2] since by a study of these it may be possible to estimate the probable weakness or abundance of the rain on the Abyssinian tableland for a few weeks in advance. Without going so far as forecasting in the early summer that a good, moderate, or poor Nile flood is to be expected, a state of precision which will not be reached for many years to come, there is a very reasonable probability that a good estimate can be formed of the Abyssinian rainfall for some 15 or 20 days in advance, and as experience is gained it may be possible to give longer notice than this.

This has been done tentatively for the flood seasons of 1904 and

[1] Mainly taken (by the kind permission of the Council) from a paper read before the Research Department of the Royal Geographical Society. Geog. Jour. Sept., Oct., 1905.

[2] Taken by the kind permission of the Council of the Royal Society from a paper on "The Relation between variations of Atmospheric Pressure in North-East Africa and the Nile Flood" Proc. Roy. Soc., Vol. A. 76 1905, p. 66-86.

1905 with considerable success, but it must be admitted that in both these years, the meteorological conditions were markedly unfavourable to heavy rainfall and remained steadily so throughout the summer; in years when more variations occur it will be more difficult to draw reliable conclusions.

In the first place, by watching the northward extension of the rain-belt in the months of March and April over East Africa, Uganda and the southern Sudan it it not difficult to estimate whether the early rains on the southern part of the Abyssinian plateau will be late or early, and some idea can usually be obtained of their strength or weakness by noting the amounts measured at stations on the Bahr el Jebel and the upper White Nile, as well as by the first indications of the rise of the Sobat. Once the rains have set in over Abyssinia it appears to be mainly the conditions of atmospheric pressure over the region of north-east Africa which modify to an important extent the monsun currents which bring the moisture collected from the waters of the south Indian Ocean, while subequatorial rainfall in the early summer seems also to play its part.

The variation of the flood.—It is the regularity of the annual rise and fall, and variation of the volume of the Nile flood from year to year which may be said to be the most striking features of the Nile regimen. A promise of a plentiful flood may be unfulfilled, and a deficiency in the early months of the rise is some times followed by an excessive supply in the autumn; at one period high and low floods seem to alternate, at another year after year of low floods prevent all cultivation of high land, or a series of good floods enables all parts to be irrigated with ease.

The narrow margin, 4 cubits or about 2 metres, which exists between a bad and a good Nile flood has been noticed by all writers on Egypt and the Nile from the time of Herodotus.[1] This small range of the flood level and the great regularity with which the rise takes place from year to year, with a difference of a few days only, are features in the regimen of the river the cause of which is not difficult to trace in the geography and the climate of the Blue Nile basin. The first is due, partly, to the long 1500 kilometres reach of the river from Berber northwards without a single tributary, in which the sudden rises in the higher reaches are gradually lost in the steady flood rise, and partly because all the tributary streams take their

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[1] Herodotus, Bk. II, 13.

rise on the Abyssinian plateau and are fed by a short, heavy rainfall of about 1000 millimetres in four months, as an average value.

The majority of large rivers are supplied by a net-work of tributary streams which extend far throughout the basin where, probably, different climatic conditions or geographical features, such as mountain ranges, affect the rainfall so as to produce the greatest precipitation at different seasons in different parts of the basin. Thus it often happens that the rise of a great river is due normally to rainfall over a portion only of its basin, and when exceptional rainfall takes place over other portions at the same season, different tributaries, which usually rise in flood successively, will be in flood at the same time, and so cause destructive inundations.[1]

As has been seen, the White Nile contributes but a feeble quantity to the flood since its waters are ponded back by those of the rapidly rising Blue Nile. In the Blue Nile basin all the tributaries rise in May or June, are at their maximum at the end of August or early in September, and then fall rapidly. This is because they all drain a comparatively small area which has a sharply defined rainy season. The same applies to the Atbara which drains the northern part of Abyssinia and in general character is much like the Blue Nile, except that its basin has a shorter rainy season and a lighter rainfall. Thus the variation in volume is due to the variation in the run-off of a single basin which is not an exceptionally large one, (552,200 square kilometres, see p. 9).

The moisture-laden air of the south-east trade winds, blowing across the equator towards the low pressure area to the north of it, is the primary cause of the Abyssinian rainfall, and consequently of the Nile flood. Depending on the annual movement of the sun from south to north and then from north to south,[2] in an area where there are no mountain ranges except the Abyssinian plateau to complicate the conditions, the rains set in over the Sudan and Abyssinia each year with great regularity, and cease with equal punctuality.

The secondary causes which determine the variations in this rainfall, and consequently in the Nile flood from year to year, are not so apparent. There are probably several of them which act with more or less effect in different years under the varying meteorological conditions existing over Africa and the Indian Ocean, but up to the present one of the most important seems to be the variation of the atmospheric pressure over north-eastern Africa.

In a previous chapter the principal features of the annual flood of

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[1] Morrill, The Floods of the Mississippi. Washington 1897.

[2] See Chap. I. p. 11.

the Blue Nile and the Atbara have been set forth, while the records of the heights reached by those of past years have been kept at Aswan and Cairo with considerable care. If there should be any regular alternation of high and low floods of moderately short period these data should show some trace of it, and it should be fairly well marked to be of any practical value in anticipating the character of a coming flood.

Nile Gauge Records.—The data available for a discussion of the Nile floods are not inconsiderable, but the greater part of them are, unfortunately, of very unequal value on account of the irregularity of the readings at the Roda nilometer, [1] and of the falsification of its records, which is stated to have taken place in earlier times in order to increase the revenue. They may be summarised as follows:—

1. Readings of the Roda nilometer from 700 A.D. to 1905, but the readings for many years are missing [2] (see p.) and since the Delta Barrage has been in use the low-stage readings have been affected by the artificially raised water-level.
2. Readings of the Nile gauge at the Delta Barrage from 1846 to 1878 (see p.).
3. Readings of the Nile gauge at Aswan from 1869 to the present time (see p. 289).
4. Readings of the Nile gauge at Wadi Halfa from January, 1890, to the present time (see p. 282).
5. Readings of the Khartoum Nile gauge from 1869 to 1883, and from 1900 to the present time (see p. 261).

The Aswan series of gauge-readings is the most complete, and will be used as the basis of this discussion. At the present time it may be considered that the Aswan dam, though its open sluices admit as free a passage of the flood-waters as possible, affects the old gauge, which is some 5 kilometres down-stream of it, and renders comparisons between readings at the present and those previous to 1901 unsatisfactory; but the gauge at Wadi Halfa has been in existence since 1890, and can therefore be used to confirm and complete the Aswan records.

The Aswan and Halfa gauges have a great advantage over those situated lower down the river, in that the whole flood of the river must pass in the river-channel at these points. Lower down the valley the flood-level of the river rises above the level of the country, and in years of high flood the embankments which should retain the water in their bed may be breached; thus a lower gauge-reading will be recorded

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[1] At Cairo.

[2] A careful collection of these from all available sources is about to be published by Amin Bey Sami, of the Ministry of Public Instruction, Egypt.

in the vicinity than if the whole flood has been confined to the river-channel. Also the normal flooding of the cultivated lands above Cairo takes a large amount of water from the river at the time of highest flood, so that the maximum range of the flood is not as high in the years when the Roda or Delta Barrage gauges have to be used as if only Aswan or Wadi Halfa readings could be employed. Since, however, the Aswan readings are available from 1869 only, it is necessary to employ those of the Roda gauge at Cairo from 1825 to 1870; before this there is a period of twenty-four years for which there are no records.

Therefore, by utilizing the Roda gauge-readings from 1825 to 1872, and the Aswan gauge-readings from 1869 to 1902, and the Wadi Halfa gauge for any subsequent years, we have a series of maximum readings of the Nile flood for 80 years, which are very fairly accurate, since for almost every year there was another gauge which was simultaneously recording the river-levels:—

Period	Gauge	Verified by
1825–1845	Roda	Barker, Holroyd, Bowring, Curzon, etc.
1846–1872	Roda	Delta Barrage gauge.
1869–1902	Aswan.	Roda, Barrage, and other gauges.
1890–1904	Wadi Halfa ..	Aswan and many other gauges.

These maxima may be graphically represented by plotting them as differences from the mean value of the series, as has been done in Plate XLIII.

Gauge-readings furnish only the level of the water surface from day to day, and not the volume of the water flowing past, which is really required. At Aswan a number of discharges were measured and a discharge-table computed, by which the volume flowing past that point at any given reading of the gauge could be determined.[1] At Khartoum on the Blue Nile, and at Dueim on the White Nile, and on the Atbara discharges have been measured in 1902 and 1903, from which the volume of the floods of these years can be calculated with fair accuracy; these have been already discussed.

The volume discharged by the Nile in flood represents the surface run-off of the rainfall of the catchment basin, while that of the rest of the year is due to what has percolated into the ground and fed the springs; it is, therefore, the volume discharged by the river in flood

[1] "Perennial Irrigation." App. III. Table I. Cairo, 1894.

which should be used in comparing the floods of different years, and the maximum gauge-readings of different years do not accurately represent this. As, however, it will be necessary to discuss as long a series of floods as possible to see if they show any trace of periodicity, whether a group of years of low flood is followed by a group of years of high flood, with any regularity, it will be necessary before 1869 to employ the records of the Roda nilometer or those taken at the Delta Barrage.

When discharge observations are not available, the floods of various years can be represented in the following manner, which is more accurate than the maximum gauge-readings if daily readings have been taken. Five-day means[1] of the readings are taken for each year, and the average reading of each five-day period for all the years is taken; then the difference between a five-day mean of any year and for the mean for the corresponding period of the series of years will show when the flood is above or below the average for each such five-day period. The sum of these differences furnishes a good means of comparing the different floods, though it is inferior to actual measurements of the discharge, since by using the sum of these differences it is assumed that the discharge increases in direct proportion to the rise of the gauge, whereas the discharge increases more rapidly, and a 0·10 metre rise at flood stage corresponds to a larger volume of water passing than a rise of the same amount at a lower stage of the river, while a gauge reading on a rising stage represents a larger discharge than the same reading on a falling stage.

It is however, necessary to employ the maximum reading as a basis of comparison between the floods of different years before 1869, and if the relation between the floods of the years 1869-1902 be examined as shown by:—

(*a*) The volume of water discharged between July 1 and October 31,

(*b*) The sum of the differences between the five-day means and the average five-day mean between July 1 and October 31,

(*c*) The maximum gauge-readings,

it will be found that the curves representing the relative magnitudes of thirty-four Nile floods at Aswan according to the three methods above described closely follow each other. Taking the curve of the "volumes discharged" as the most accurate, the curve of "differences from mean gauge" follow it closely, being sometimes slightly above it, at other times slightly below it. The agreement of the curve of

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[1] That is 1-5, 6-10, 11-15, 16-20, 21-25, 26 to the end of the month, as have been given for Wadi Halfa on p. 282.

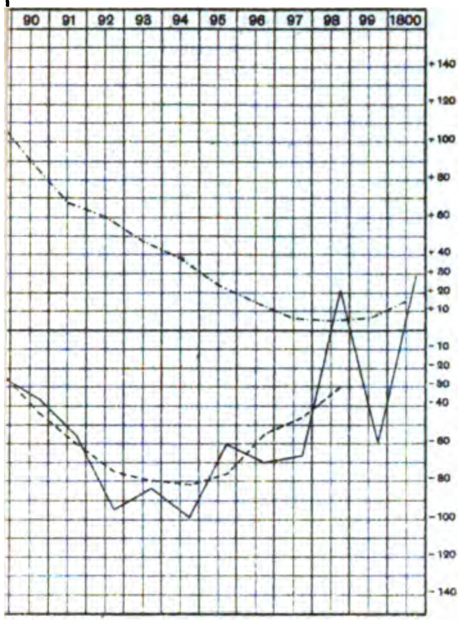
"maximum gauge-readings" is less satisfactory, as would be expected; though it usually agrees fairly well, on one or two occasions it differs markedly; for instance, in 1881, 1882, and in 1896. However it may be claimed that, for the purpose of the present investigation, the curves of "differences from mean gauge" may fairly be used as a close approximation to the volume discharged for places such as Wadi Halfa and Khartoum 1869-1880, where daily readings for a series of years are available, while the curve of maximum gauge-readings will reproduce generally the shape of "volume discharged" curve, though occasionally diverging from it to some extent. It is the "maximum reading" curve alone which is available for Roda and the Delta Barrage observations.

We therefore possess fairly reliable records of the maximum readings of the Nile floods for eighty years past. As far as 1846 these records can be controlled by the records of other gauges, and before that date the contemporary evidence of travellers and residents enables us to verify several of the more important years. These data should show some signs of an alternating series of high and low floods, that is of a periodicity in the floods, if such does exist. Brückner has shown a periodicity in rainfall of thirty-five years from maximum to maximum, which he traces generally throughout the continental areas of the world, and which might be expected to appear here also.

In examining the Nile floods records for traces of periodicity, it must be remembered that it is the variation of the Abyssinian rainfall which is really being discussed, and the flood is used as being a convenient expression for the run-off, which is assumed to bear a fairly constant proportion each year to the rainfall, though this is not strictly true. In years of heavy rainfall the ratio of run-off to rainfall will be higher, and in a year of drought it will be lower, than in a normal year.

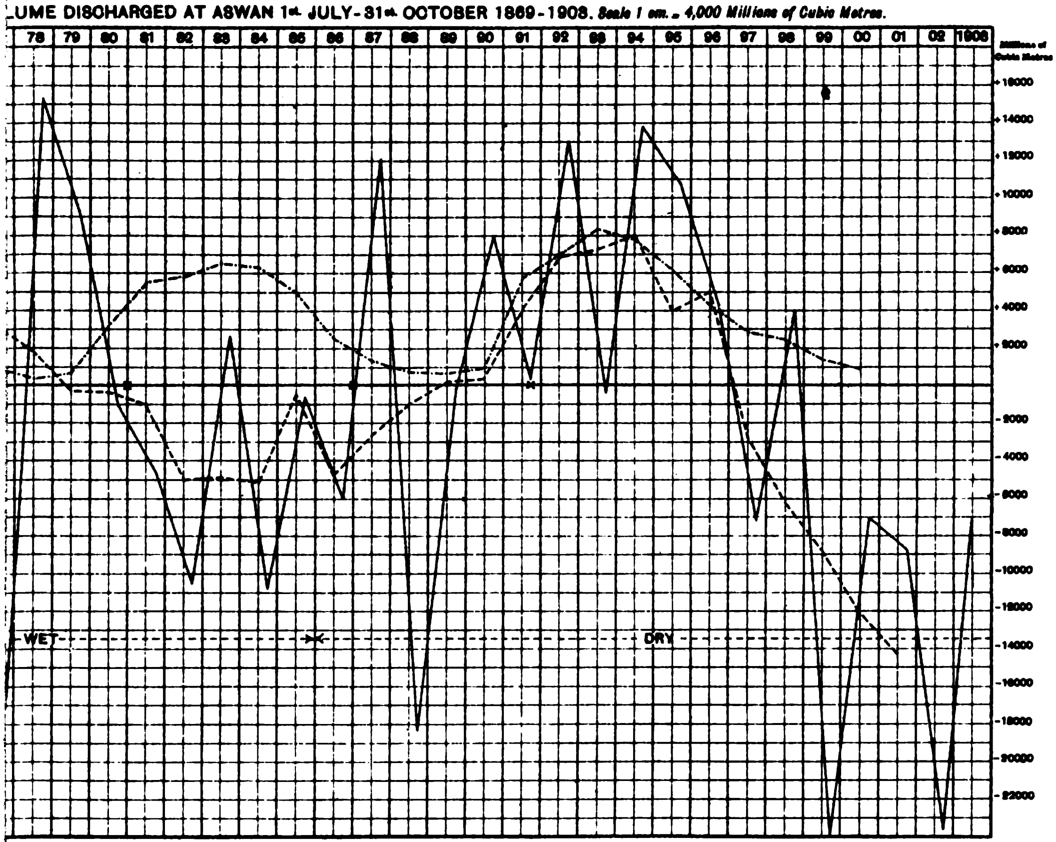
In seeking for evidence of periodicity in a long series of observations it may be helpful to eliminate as far as possible small accidental variations which may otherwise hide the periodical variations. This is conveniently done by taking successively the means of groups of five years, and then comparing these mean values. For studying the effect of varying meteorological conditions the yearly values are necessary, and in the tables of the volume discharged at Aswan, and the maximum gauge readings at Roda and the Barrage both the yearly values and the five year means are given; the former being more useful in studying the effect of the meteorological conditions and the possibility of prediction, while the latter concerns the question of periodicity.

On plate XLIII the Nile floods for the 78 years 1825-1903 are shown



ER WITH SUNSPOT CURVE.

UME DISCHARGED AT ASWAN 1st JULY-31st OCTOBER 1869-1903. *Scale 1 cm. = 4,000 Millions of Cubic Metres.*



1869-1903 { *Flood volume*
5 year means of flood volume
Wolf's Sunspot curve; Met: Zeit: 1903. p. 197.

as well as an earlier series of 64 years from 1737 to 1800. Up to 1872 the variation of the maximum reading of the Roda gauge from the mean[1] is plotted on the scale of 1 : 20, but from 1869 to 1903[2] the variation of the volume discharged in each year's flood from the mean value for the 32 years 1869-1902 is plotted on the scale of 1 centimetre to 200 millions of cubic metres. Over this record of the yearly flood is plotted the curve of the five–year means,[3] the mean value for each five-year group being plotted under the middle year of the group.[4]

In the first place, the more reliable series 1825-1903 will be examined, for any sign of a regular alternation of groups of high and low floods will have a greater value here than in the older series, being obtained from more reliable data. The five-year mean curve shows a certain alteration; low periods occur as follows:—

	Duration.	Intervening period.
1829-1848	19 years	
		8 years.
1856-1860	4 „	
		21 „
1881-1888	7 „	
		9 „
1897-1902	5 „	

But these intervening high-flood periods are broken by groups of years which reduce the curve to the normal line, as in 1843-46, 1855-56, and 1867. To take the Aswan observations 1869-1903 alone, an apparent periodicity of about seventeen years from maximum to maximum occurs, but in the preceding years no trace of such period is to be found.

Fritz,[5] when discussing the Roda series 1825-1872 and the Delta Barrage series from 1846-1878, believed that a relation could be made out between the high and low Nile floods and the maxima and minima of the sunspot curve, and Waite[6] has recently maintained the same. On Plate XLIII the sunspot curve has been plotted from the numbers given by Wolfer,[7] but it does not appear to bear any definite relation to either the five-year curve or the yearly flood curve; the maximum of 1837 coincided with a group of particularly low floods, that of 1846 with a high-flood period. In 1860 the sunspot maximum occurred just before the high floods of 1860 and 1861, and after the low years of 1857-59; the low sunspot maximum of 1883 occurred at

[1] Column 4 of table on p.
[2] Column 4 of table on p.
[3] Tables on p.
[4] The mean of 1871-1875 is plotted under 1873, and that for 1872-1876 under 1874, and so on.
[5] Met. Zeit., Bd. 13, p. 363; and Bd. 15, p. 303.
[6] Scot. Geog. Mag., 1904, p. 487.
[7] Met. Zeit. 1902, p. 193.

the time of a group of low floods, and the improved Nile supply came in 1887, 1889 and 1890, when the sunspots were at minimum. Whatever connection may finally be worked out between sunspots and meteorological phenomena, it seems clear that the Abyssinian rainfall is due to the combined effect of causes which usually prevent any coincidence between high and low floods and the maxima and minima of the sunspots which may exist, from being recognized, and to predict improved floods on the basis of an approaching sunspot maximum seems to be going further than the evidence warrants.

In 1900, Sir N. Lockyer F. R. S. and Dr. W. Lockyer[1] discussed periodical pulses of rainfall, which they distinguished as + and − pulses connected with + and − heat pulses of the solar weather cycle.

As a result of an examination of the spectra of sunspots and of the rainfall of India and Mauritius, they concluded that India has two pulses of rainfall, the one near the maximum and the other near the minimum of the sunspot period, and that the dates of the beginning of these two pulses are related to sudden changes in widened lines of the spectra. The famines of India for the last half-century were found to occur in the intervals between these pulses, and the lowest Nile floods between 1849 and 1878 are said to have occurred between the same intervals. These pulses are given as follows :—

— Pulse.	Mean condition.	+ Pulse.
	1869	1870–5
	1876	
1877–80		
	1881	
		1882–6
	1886–7	
1888–91		
	1891–2	
		1892

According to this view, then, low Nile floods should predominate about 1869, 1876, 1881, 1887 and 1892, while high floods should follow the years of the + and − pulses. They deal briefly with some of the Nile floods in this paper, pointing out that "the highest Niles follow the years of the + and − pulses."

1871	flood, 1 year after the + pulse of 1870.					
1876	„	2	„	subsidiary pulse of		1874.
1879	„	2	„	„	„	1877.
1883–4	„	1 and 2 years after the + pulse of				1882.
1893–4	„	1 „ 2	„	„	+ „	1892.

[1] Proc. Roy. Soc., vol. 67, p. 409.

It does not seem, though, that such a direct and simple relation can be made out for the Abyssinian rainfall; the 1871 flood was less than those of 1869, 1870, or 1872, while 1874, and not 1876, was the big flood to compare with the pulse of 1874, and 1878 was a year of heavier rainfall than 1879, and particularly a very late rainfall, extending far into the autumn; 1883 and 1884 were moderate and rather low years respectively. These discrepancies are mentioned to show that the dates of the + and – pulses by themselves do not consistently precede specially high floods, and therefore this periodicity of five or six years is not traceable in the yearly or five-year Nile curves.

The low Nile floods quoted are those of 1858-9, 1868, 1873, 1877, but it should be noticed (see Plate XLIII) that the floods of 1858-9 were not especially low; 1857 was almost as low as 1858, and 1855 was lower than either; 1868 was a very low year, but 1864 was almost as low; 1873 was a low flood, and 1877 a very low flood. Turning to the other "mean condition" years which should coincide with low floods, 1881 was a normal flood, 1887 was a good flood, though 1888 was a bad one, and 1892 was particularly good, 1888 and 1899 being the nearest bad years to this date.

It would seem, therefore, that Egypt and Abyssinia form an area in which the meteorological conditions are not regularly consonant with those of India discussed by Sir N. Lockyer; at times agreeing and at other times varying widely, the solar weather is as yet an uncertain guide in the study of Nile floods.

Turning now to the yearly curve for the seventy-nine years from 1825 to 1903 in Plate XLIII, the most marked feature is the way in which the flood varies, passing from a value above the normal to one below it in almost successive years. It is this irregularity, this rapid oscillation of the curve, which makes of small practical value any argument based on a periodicity shown by the five-year curve; for in the most regular group of low floods, a high flood may intrude itself, as 1829 and 1834, also 1887; while 1873 and 1877 were very low floods among a group of floods all much above the average. If this series of floods be examined, we shall see that from 1825 to 1903 the succession is as follows:—

In seventeen cases a flood *above* the average is followed by one *below* the average.

In eighteen cases a flood *above* the average is followed by one *above* the average.

In twenty-one cases a flood *below* the average is followed by one *below* the average.

In sixteen cases a flood *below* the average is followed by one *above* the average.

Even in periods when high or low Niles greatly predominate, such as 1825-1839 or 1860-1880, floods of opposite character frequently occur, *e.g.* the high flood of 1829 in the first period of low floods, and the low floods of 1864, 1869, and 1877 in the high flood period of 1860-1880.

In these seventy-eight years—

2	successive	years above	the average	occur	three times.
3	„	„	„	„	„
4	„	„	„	„	„
2	„	below	„	„	once.
3	„	„	„	„	three times.
4	„	„	„	„	twice.
5	„	„	„	„	„

of which the last two groups belong to the low-flood periods of 1825-1839 and 1899-1903.

Since the Nile flood is the direct result of the June-September rainfall on the Abyssinian tableland, the rains and the meteorological conditions which determine them must be subject to a similar oscillation to that which is so markedly shown in the flood diagrams. Essentially the succession of Nile floods for the last eighty years is an oscillation between floods above the average and floods below the average, and the same thing is seen in the series from 1737 to 1800, though the range of the oscillation is not so large if the observations can be relied on.

The long series of years following 1738 in which the Nile flood was almost invariably good is corroborated by Bruce, who writes, "The Nile for these thirty years has but once so failed as to occasion dearth, but never in that period so as to produce famine in Egypt."[1] This refers apparently to the thirty years previous to 1773,[2] the low Nile being perhaps that of 1772. He further speaks of three of these floods having been exceptionally abundant, which would apply to those of 1757, 1758, and perhaps 1753. The exceptionally low floods of 1783 and 1784 are mentioned by Volney,[3] who speaks of them as causing a serious famine.

For comparison with this earlier series of years, rainfall data do not exist as for the nineteenth century; still, it can be said with certainty that the curve is not one which shows any more similarity to the

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[1] Travels to discover the Source of the Nile, 2nd edit., vol. 5, p. 375, London, 1805.

[2] Ibid., p. 412, note.

[3] "Voyage en Egypte et en Syrie," 5th edit., vol. 1, p. 157, Paris, 1822.

alternating dry and wet groups of years having a period of about thirty-five years, than has been found in the later series.

We may conclude, then, with reference to the variation of the Nile flood from year to year, that no trace appears of any such definite periodicity as might be of assistance in estimating the probable duration of any succession of high or low Nile floods.

In the sixty-four years (1736-1800) of the eighteenth century, the oscillation between excessive and deficient floods is on the whole much the same as for the nineteenth century.

In thirteen cases a flood *above* the average is followed by one *below* the average.

In twenty cases a flood *above* the average is followed by one *above* the average.

In eighteen cases a flood *below* the average is followed by one *below* the average.

In twelve cases a flood *below* the average is followed by one *above* the average.

2	successive	floods	above	the	average	occur twice.
3	"	"	"	"	"	"
4	"	"	"	"	"	three times.
5	"	"	"	"	"	once.
2	"	"	below	"	"	three times.
3	"	"	"	"	"	once.
6	"	"	"	"	"	"
10	"	"	"	"	"	"

The long period from 1781 to 1799, when apparently all floods except two were below the average, prevents any average length of the oscillation between floods in excess or defect being estimated satisfactorily.

Essentially, then the Abyssinian rainfall, which is represented by the Nile flood, fluctuates at short intervals, and does not increase more or less regularly for a period of years, and then decrease in a similar way. These fluctuations are short, and if the number of years between the different crests of the curve is taken (whether such crests rise above the average or not), the length of time between such crests is:—

2	years in	twelve	cases in the	nineteenth	century.
3	"	six	"	"	"
4	"	three	"	"	"
5	"	four	"	"	"
2	"	five	"	eighteenth	"
3	"	two	"	"	"

4 years in four cases in the eighteenth century.
5 „ two „ „ „
8 „ one case in the „ „
11 „ „ „ „ „

We have, therefore, to deal with a comparatively short-period variation in the meteorological conditions, but this subject requires further investigation.

It has been seen that high levels in the Bahr el Jebel, the White Nile and the Blue Nile depend upon very different factors, and in the past much misunderstanding has been due to this. Before dealing with the meteorological conditions which probably affect the Nile flood, it will be useful to compare such records as exist of the Bahr el Jebel and White Nile (see p. 102) with the corresponding Blue Nile flood in order to see the effect of the various sources of supply.

Year	Bahr el Jebel, etc.	Blue Nile	Equatorial lakes.
1848–9	Exceptionally low in winter.	Good flood.	Lake Albert must have been very low.
1850	„ „ „ January	„ „	
1853	Low at Gondokoro in January	„ „	
1858	Summer rains feeble	Poor „	....
1859	Water in April very low. Early rains poor but later very heavy.	„ „	Lake level probably low.
1861	Rains late but exceptionally heavy ..	High „	Lake probably rising.
1862	Bahr el Ghazal rains heavy.	Average flood	....
1863	White Nile said to be low in January. Bahr el Ghazal high in February.	Late, probably Sobat flood was the same	....
1864	White Nile lower in March than in 1863.	Very high flood	....
1868	Rains feeble	Low flood	....
1871	Drought at Gondokoro.	Good flood but fell rather early	....
1872	Good season, high flood at Gondokoro.	Good flood fell rather late.	Lake probably rising.
1877	Gondokoro, no rain river low	Very poor flood	....
1878	Exceptionally high flood	Very high „	Lake Victoria high.
1879	River high till November	High late „	„ „ „
1880	Bahr el Ghazal rains heavy.	Average „	....
1882	Rains feeble till July	Poor „	....
1883	Heavy rains high flood.	Moderate „	Lakes probably high.
1888	....	Very low „	....
1889	....	Average „	Lake[2] low.
1890	....	Good „	„ „
1891	....	Average „	„ „
1892	....	High „	„ high.
1895	....	Good „	„ „
1896	....	Fairly good „	„ inclined to fall.
1897	....	Poor „	„ „ to rise.
1898	Low stage level rather low[1].	Fairly good „	„ steady.
1899	„ „ „ lower[1].	Very low „	„ fell rapidly.
1900	„ „ „ „	Poor „	„ very low.
1901	„ „ „ low[1]	„ „	„ rose slightly.
1902	Good rain..	Very low „	Lakes very low.
1903	Low in April / High flood	Low „	„ rising.
1904	Low stage higher than usual	Very low „	„ high.
1905	Very feeble rains	„ „ „	„ falling.

[1] Delmé-Radcliffe, Geog. Jour., Nov. 1905, p. 484.

[2] Though these data from 1889 refer specially to Lake Victoria, it is highly probable that Lake Albert varied similarly.

The level of Lake Albert determines the low stage level of the Bahr el Jebel after the rainy season, and at flood stage may produce exceptionally high levels (see p. 91). Thus we may say with confidence that this lake, and consequently the equatorial lakes in general, was low in 1848-9, 1850, 1853, and 1859 while it was probably high in 1861, 1872 and 1883. In this last year the extensive flooding at Lado recorded by Emin Pasha must have been partly due to a high lake level. Heavy rains are recorded in both the Abyssinian and Bahr el Jebel areas in 1861, 1872, 1878 and 1879 while feeble rains affected both in 1858, 1868, 1877, 1882, 1899 and 1905.

In some other years precipitation in each of these regions seems to have differed entirely in character, *e.g.*, 1859, 1871, 1883, 1902 and 1903. Besides the effect of the lake, which will maintain its level for a time after years of heavy rainfall have passed, and rise slowly after a series of dry years has ended, it is certain that precipitation on the Bahr el Jebel and in Abyssinia may differ greatly, and it is not safe to assume that a high Nile flood supplied by the Blue Nile corresponds to high levels in the Bahr el Jebel though it may do so.

In April, 1901, the lagoons and flooded depressions in the Bahr el Jebel valley were much larger than in April, 1903, when large areas of what was open water in the former year had become covered with a growth of reeds. This result is remarkable in view of the fact that no special fall in the low-stage river level at Gondokoro in 1903 had taken place, indeed it was higher than in 1901, and the rainy season of 1902 had been an unusually heavy one. It is possible that such depressions often do not communicate freely with the main stream, and, having been filled in years when sadd-blocks were interfering with the normal drainage, their level only fell slowly when the blocks had been removed; the rains of 1903 accompanied by a high lake-level refilled many of them by 1904.

Effect of Atmospheric Pressure.—One meteorological factor, the atmospheric pressure, has been found to vary over north-eastern Africa inversely to the Nile floods, and consequently to the Abyssinian rainfall, with such regularity, that a further study of the subject is being undertaken. The relation of pressure variations to precipitation and the similarity of such variations over wide areas have been studied by several investigators.

In presenting the evidence of variation of climate,[1] Brückner has

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[1] "Klimaschwankungen," Vienna, 1890 p. 218.

shown that in every period of greater rainfall there is a reduction of the differences of atmospheric pressure between stations, while in every dry period there is an increase, and these variations occur both in the differences of pressure between one station and another, and between different seasons.

Sir N. Lockyer and Dr. W. J. Lockyer have discussed periodic variations of pressure in a series of communications to the Royal Society, [1] wherein they point out that these variations of pressure over the Indian Ocean and neighbouring regions are inverse in character to those which occur in the American area, while certain other regions are intermediate in type.

Dr. F. H. Bigelow has recently dealt with [2] the synchronism of the variations of the solar prominences with terrestial atmospheric pressures, and concludes that "the phenomenon of inversion prevails in the earth's atmosphere, localizing the effect of solar action in two typical curves which are the inverse of one another." The distribution of his direct, indirect, and indifferent types agrees closely with that published by Sir N. Lockyer [3] in his paper "On the Behaviour of the Short-Period Atmospheric Pressure variation over the Earth's Surface."

In 1895, Sir J. Eliot published [4] a preliminary discussion of oscillatory changes of pressure in India, and showed that [5] well-marked oscillations having a period of more than a year, occur over the Indian area, and are directly related to the character and distribution of precipitation over the Indian monsun area, and to the great atmospheric movements over India. Recently, Professor J. Hann has studied [6] the relation between the variations of pressure in Iceland and the weather conditions in north-western Europe.

A discussion of all available data concerning the Abyssinian rainfall [7] shows that the distribution of rain in the different months of the summer is approximately as follows:—

June.	July.	August.	September.
13 per cent.	30 per cent.	32 per cent.	13 per cent.

[1] On some Phenomena which suggest a Short Period of Solar and Meteorological Changes, Proc. Roy. Soc., vol. 70, p. 501

[2] Monthly Weather Review, November, 1903, p. 509.

[3] Proc. Roy. Soc., vol. 73, p. 457, 1904.

[4] Indian Meteorological Memoirs, vol. 6, Part II.

[5] Loc. cit., p. 117.

[6] "Die Anomalien der Witterung auf Island in dem Zeitraume 1851 bis 1900 und deren Beziehungen zu den gleichzeitigen Witterungs-anomalien in Nordwest-Europa," Sitzungsberichte d. k. Akad. Wiss. in Wien,' 1904.

[7] p. 212.

the remaining 12 per cent. falling in March, April, and May. As the flood wave caused by rainfall in the basin of the Abai or Blue Nile takes from 25 days in July to 15 days in September to reach Aswan,[1] we may consider that the meteorological conditions which we have to examine are those of June, July, August and September, the months of heaviest rainfall on the Abyssinian plateau.

Summer Pressure Anomalies and Flood Conditions.—If the variations from the mean of the atmospheric pressure of the summer months, June to September, for a series of years are examined (Plate XLIV), it will be seen that they exhibit an irregular oscillation which is generally inverse to that of the Nile floods; years with high atmospheric pressure correspond closely to those of deficient Nile floods, and those of low atmospheric pressure to the high floods, and consequently with heavier rainfall in Abyssinia. As has been shown by Brückner, Lockyer, Bigelow, and others, such oscillations of pressure are to be traced over very wide areas, high or low pressures occurring at nearly the same time in the observations recorded at distant stations. The data which are available for an investigation of the pressure conditions occurring over the Nile basin itself are few, since temperature and rainfall have been more often recorded than atmospheric pressure, for which only a few year's observations in the Nile valley, south of Cairo, and in the Sudan exist as yet; still the observations which are available at Cairo and Alexandria from 1869, and Beirut from 1875, may be utilized to compare the pressure conditions of north-eastern Africa with those of more distant stations.

Taking, now, the summer or low pressure months, June to September, which include the period of rainfall in Abyssinia, the mean value of the barometric pressure is usually above the normal value for these months (as deduced from the 36 years, 1869 to 1904), when the Nile flood is below the average, and below it when the flocd is above the average in this series of years; a mean atmospheric pressure for June to September in excess of the normal occurred with twelve low floods as compared with four high floods, while a deficient mean pressure occurred with thirteen high floods and five low floods.

The agreement is more clearly shown if the curves of the mean pressure anomalies and of the Nile floods (inverted) are compared. It will then be seen that not only do excess pressures and deficient floods, and the converse, occur with considerable frequency, but also that the differences from the normal of the two curves, show a marked tendency

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[1] p. 232.

to move in the same direction, although the amount of excess or deficit for any year in the atmospheric pressure may not bear any definite relation to the magnitude of the flood. Of 18 years, in which there was an increase in the mean pressure of June to September, there was a decrease in the flood as compared with the previous year in 16 years and in 2 years there was an increase; in 14 years, in which there was a decrease in the barometric pressure as compared with the previous year, 9 years had an improved flood and 5 years had a worse flood. Therefore, though there is not an exact agreement between the curve of the mean atmospheric pressure for April to September at Cairo, and the inverted curve of the Nile floods, there is considerable similarity, which is worth further investigation.

The years in which the agreement is wanting, when the mean summer pressure for April to September and the flood are compared, are:—

YEAR	Pressure difference from preceding year	Pressure difference from normal	Flood difference in volume from previous year[1]	Flood difference from mean[1]
	mm.	mm.	Million cubic metres	Million cubic metres
1871	−0·49	−0·59	−11,800	+ 3,184
1872	+0·44	−0·15	+ 3,700	+ 6,877
1874	+0·29	+0·55	+27,600	+17,434
1875	−0·79	−0·24	−10,700	+ 6,709
1886	+0·05	+0·01	− 5,320	− 5,855
1901	−0·42	−0·00	− 1,500	− 8,661

If the investigation is carried out over a wider field, and the records of barometric pressure of other and more distant stations are utilised, this general agreement is seen to extend to many of them, also showing that variations from the normal pressure occur nearly simultaneously over very large areas.[2] The variations from the normal pressure have been plotted on Plate XLIV for the stations of

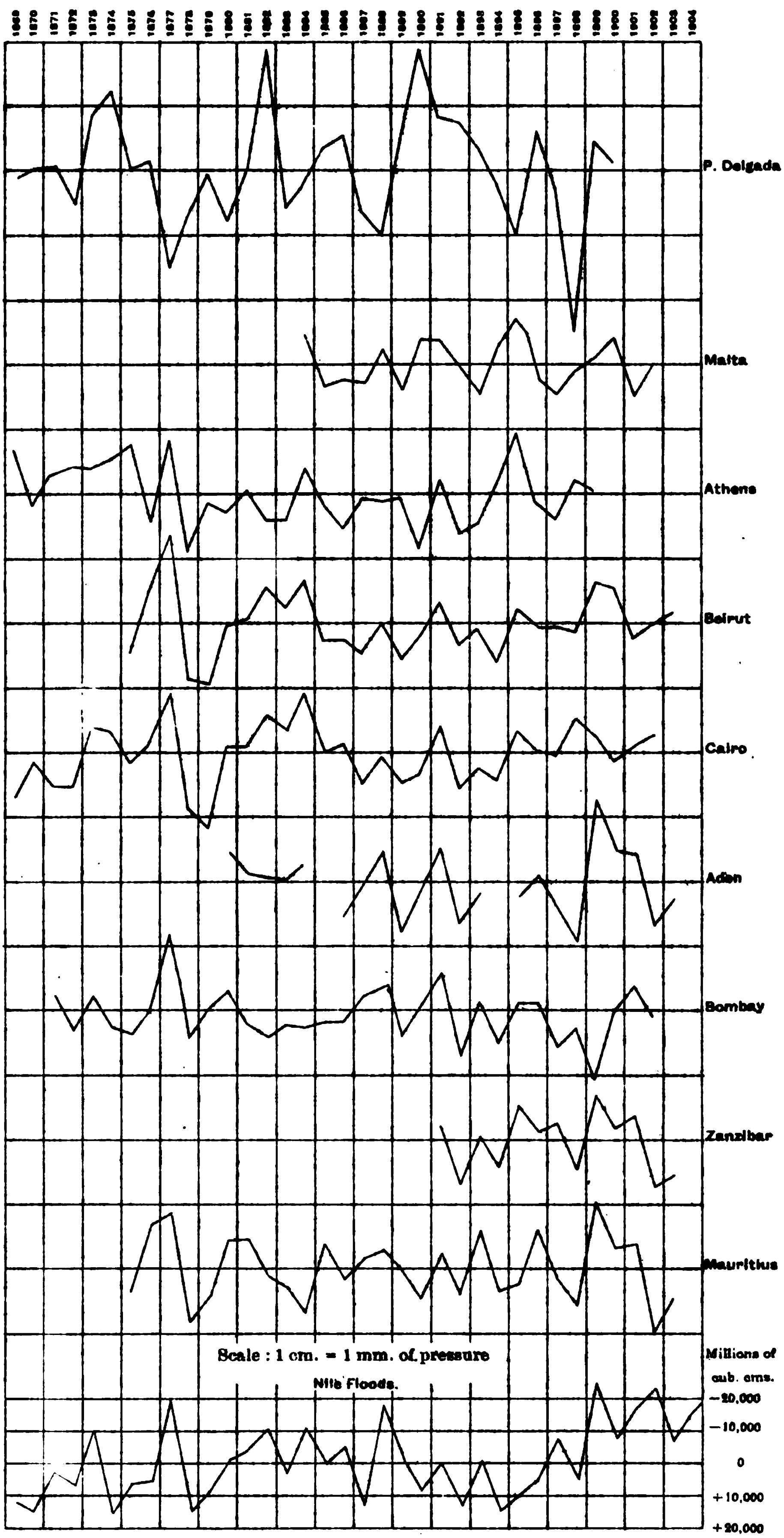
Ponte Delgada (Azores).	Beirut.	Bombay.
Malta.	Cairo.	Zanzibar.
Athens.	Aden.	Mauritius.

Here the general agreement of the maxima and minima are well shown, as well as many of the minor crests, so that it would appear that the

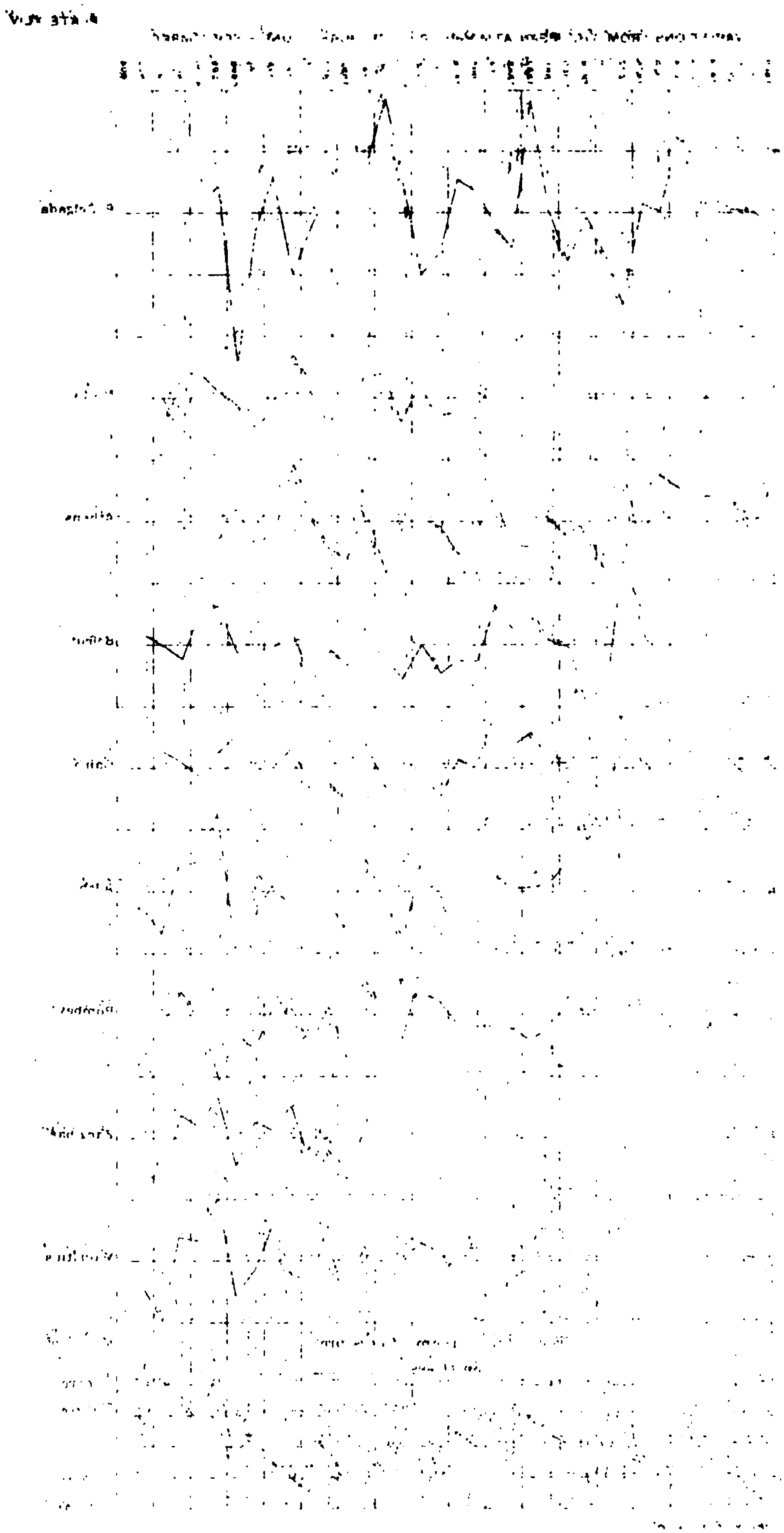
[1] The volume of the flood is taken as the volume of water passing Aswan between July 1 and October 31.

[2] See Lockyer, Proc., Roy. Soc. vol. 73, p. 457; Bigelow, Monthly Weather Review, November, 1903; Brückner, "Klimaschwankungen." Chap. VI, Vienna, 1890; Hann, Sitzungsberichte, d. k. Akad. d. Wiss. in Wien, vol. 110, III, January, 1904.

VARIATIONS FROM THE MEAN ATMOSPHERIC PRESSURE, JUNE – SEPTEMBER



SURVEY DEPT. CAIRO



barometric conditions, with which a heavy or deficient rainfall in Abyssinia coincides, are often of very wide extension. The agreement of the Cairo pressure curve with the inverted flood curve has been discussed; the Beirut curve has much in common with the Cairo curve but presents some points of iuterest; the high pressure in 1877 is well marked, coinciding with the very low Nile of that year, as it is in the Mauritius curve; at Cairo the discrepancy between the two curves is apparent rather than real, as the pressure was exceptionally high in July and August.

All the curves mark the low pressure of the summer of 1878, a year of high and late flood. In 1879 the pressure was rather higher but agrees with the flood; 1880 continues in the same direction, as also does 1881. In 1882 there are points of peculiar interest to be noted; at Cairo, and Beirut, the mean pressure increased, and in Egypt the Nile flood was feebler than in any year since 1877, these data being thus in agreement; but in Mauritius, and Aden the pressure fell considerably, the Bombay rainfall was in slight deficit, 1·92 inches, while that for India generally from June to September was 2·1 inches above normal. In 1883 a marked improvement in the flood took place, with a very slight decrease of pressure at Cairo, Beirut, Aden, but at Bombay it rose. In these two years then Indian and Egyptian pressures and rainfall conditions were not in agreement. In 1884 again the mean pressure increased at most stations and the Nile flood was bad; in 1885 the mean pressure fell at Cairo, Beirut, and it rose at Bombay; the Nile flood was slightly above the average again, while in Bombay rainfall was 3·1 inches below the average; 1886 shows rather higher pressures at Cairo and Beirut, while the flood was poorer, but Aden, and Bombay had lower pressures, and at Bombay there was a large excess of rainfall; in 1887 the conditions were reversed except that in spite of increased pressure Bombay had an excess of rainfall, but the noticeable point is that in these two years again, as in 1882 and 1883, Egypt and Western India are at variance. In 1888, 1889, and 1890 all the curves agree and the very low flood of 1888 followed by higher ones of 1889 and 1890 are paralleled by the failure of rainfall at Bombay in the first year, and the greatly reduced deficits of the next two years. Until 1895 the curves show agreement, but in 1896, 1897, and 1898 the variations of the flood are not well indicated in the Cairo and Beirut curves, and in 1897 Zanzibar alone shows an increased mean pressure.

There is some difficulty in comparing the rainfall due to the Bombay monsun current with the Nile floods, as it is doubtful which inland

stations received their rainfall from this current and which from the Bay current. On plate XLVI the percentage deviation of each year's rainfall from the normal is shown for each of the rainfall districts on the west coast of India which are certainly supplied by the Arabian Sea or Bombay current. It will be seen that in spite of an agreement in many years, there are others in which the reverse relation occurs, especially about the period 1881-9.

Sir W. Willcocks, in a paper at the Meteorological Congress at Chicago in 1892, stated that famine years in India were years of low supply in Egypt; and Sir J. Eliot, in his forecast of the probable character of the south-west monsun of 1900, supports this.[1] His latest views on the Indian monsun are fully set forth in his address to Section A (Subsection, Cosmical Physics) of the British Association, 1904.[2] He considers that local or general drought in India may be due, among other things, to a larger diversion than usual of the monsun currents to Burma or Abyssinia, and later he states that the Nile floods of the period 1895-1902 followed closely the variations of the rainfall in Western India, showing that the Abyssinia rainfall was more or less generally in defect, and most largely in 1899 and 1901.[3]

Since the tropical rains of all this region are all caused primarily by the transfer north-ward of the equatorial rain-belt, followed by the northward extension of the south-east trade winds, it follows that probably a weakness of the winds in one area may also be felt in neighbouring areas in similar latitudes. But there are other causes at work which affect the Nile flood and may cause it to depart from its usual agreement with the south-west monsun of India. The alternations of atmospheric pressure, which have been discussed above, certainly exert a modifying influence on that western portion of the south-western monsun of the Indian Ocean which provides the rain of Abyssinia, and which but for the influence of local conditions should closely follow the Arabian sea current of the monsun of India.

It would appear therefore that while the monsun conditions of Western India are closely connected with those of Eastern and North-Eastern Africa in the summer months, it is going too far to insist upon a complete agreement; deductions based on this without regard to the conditions in Northern and Central Africa are likely in some years to be considerably in error.

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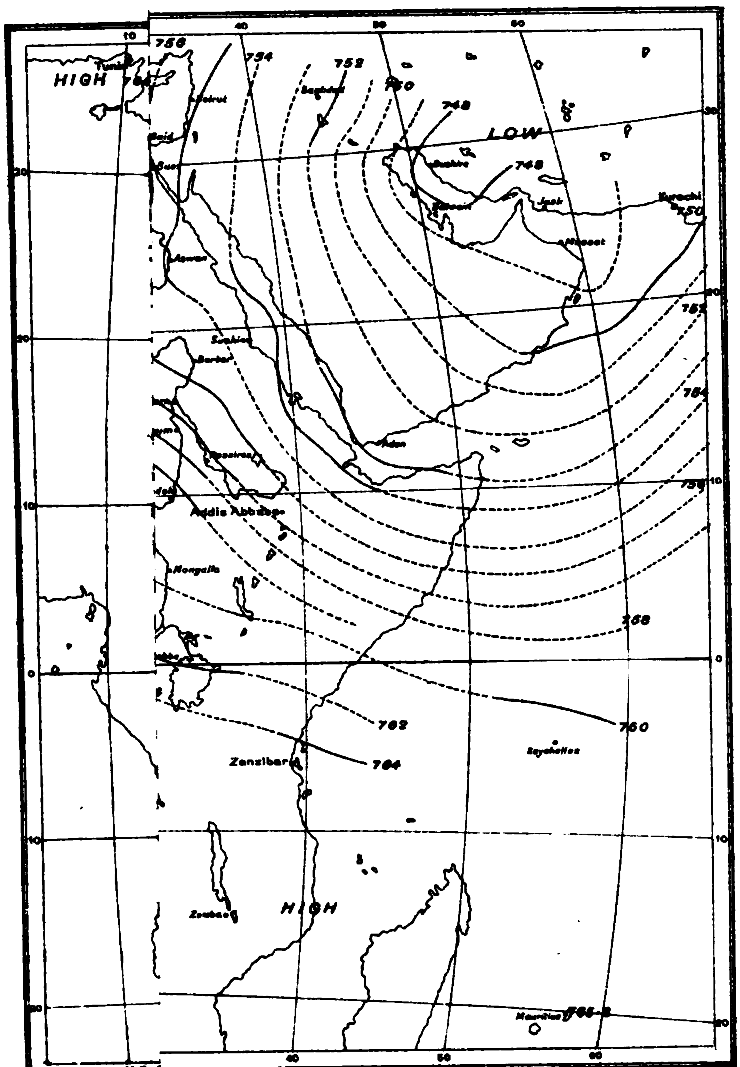
[1] "Nature," August 23, 1900, p. 392.
[2] Ibid., August 25, 1904, p. 399.
[3] This should be 1902; the 1901 flood, though below the mean, was much better than that of 1902.

UTION OF PRESSURE

JULY 1904



Survey Dept

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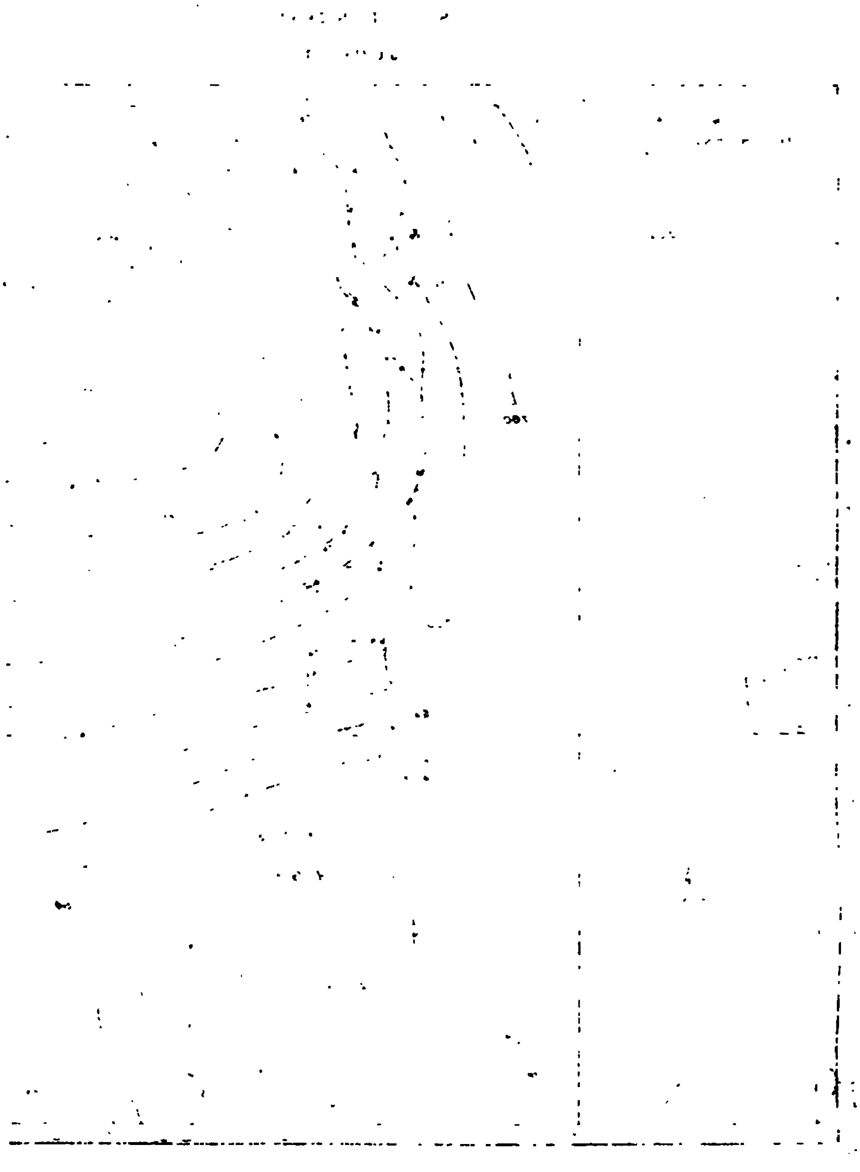


Monthly Pressure Anomalies.—So far then, there appears to be considerable probability that the variations of the rainfall in Abyssinia are connected with the variations of barometric pressure from year to year in north-eastern Africa in the summer months, that is from June to September.

When the monthly pressure anomalies at Cairo, Alexandria and Beirut are compared with the monthly excess or defect of the Nile flood as recorded on the Aswan gauge, a close agreement is found to exist. Sir J. Eliot, F.R. S., [1] points out that periodic changes of pressure in India are far smaller in amount than the annual and daily range, take place more gradually, and from their small magnitude accurate and long-continued series of observation are necessary for their discussion. Their importance is not, however, to be measured by their size ; Sir J. Eliot is of opinion that in India they are due to the seasonal mass transfer of air across the equatorial belt between southern Asia and the Indian Ocean, and, as a consequence of this, "they are directly related to the largest and most important features of the weather in India, viz., the character and distribution of the precipitation of rain and snow in the Indian monsûn area.[2] It will hardly be remarkable if a somewhat similar oscillation be found to exist in the north-eastern part of Africa, and we may expect it similarly to affect the African monsûn rainfall in Abyssinia and the Sudan.

To examine this both the crude and the "smoothed" values of the differences of mean atmospheric pressure of each month from the normal for Abbassia Observatory, Cairo, have been used. The smoothed values are obtained in the same way as in the Indian Meteorological Memoir already quoted, that is, the smoothed values for any month is the arithmetical mean between the actual values for that month, the preceding and succeeding months. The same has also been done for Athens, Beirut, Aden, Zanzibar and Mauritius. These values have been plotted on Plate XLVII to scale of 5 mm. to 1 mm. of variation of pressure from the normal, so that the correspondence between the various stations at the same season can be followed.

In studying these curves, and specially those of Beirut, Cairo, and Aden, we must remember that it is with the effect of the pressure variation during June, July, August, and September that we are principally concerned. This leads to another point; since the rainfall which affects the Nile flood is strictly limited to the Abyssinian area, high and low pressures may occur in the winter months without having any

[1] Indian Meteorological Memoirs, vol. 6, Part II, Calcutta, 1895.
[2] Ibid., p. 117.

effect on the subject under consideration, the Nile flood. This is the reason that if the mean pressures at Cairo for October to March or even January to April are examined, they show no relation to the variations of the Nile flood.

Flood conditions.—The agreement between the barometric curve for Cairo and the variation of the Abyssinian rainfall and the Nile flood, cannot conveniently be shown graphically when the monthly pressure variations are considered, because the discharge of the Nile in different months depends on different factors. After October the Blue Nile supplies a steadily decreasing amount, until in May its discharge at Khartoum may almost cease; the Sobat is at its maximum in November and decreases until it, too, supplies hardly anything in April in a low year; the combined discharge of the Bahr el Zaraf, Bahr el Jebel and Bahr el Ghazal is always a practically constant amount for the purpose of the present discussion. Although, therefore, pressure conditions might be such in November as to favour a heavy rainfall, and even though this might fall at the equatorial lakes, the Nile discharge would no more be influenced by it than conditions of excessive drought at a similar time. In short, conditions favourable or unfavourable to precipitation will affect the Nile flood supply in some such way as the following:—

April and May: advance or retard commencement of flood; June, July, August: increase or decrease flood; September, October: delay or accelerate the fall of the flood.

In other months they will have no effect on the Nile supply, since no rain is falling within the effective basin.[1] The low stage supply is due to the combined effect of the July to August rainfall, and to the September to October later rains; a heavy rainy season ceasing usually in September, and a moderate rainy season, followed by prolonged September to October rains, may both furnish a good low-stage supply drawn from the stored ground-water and the springs of Abyssinia.

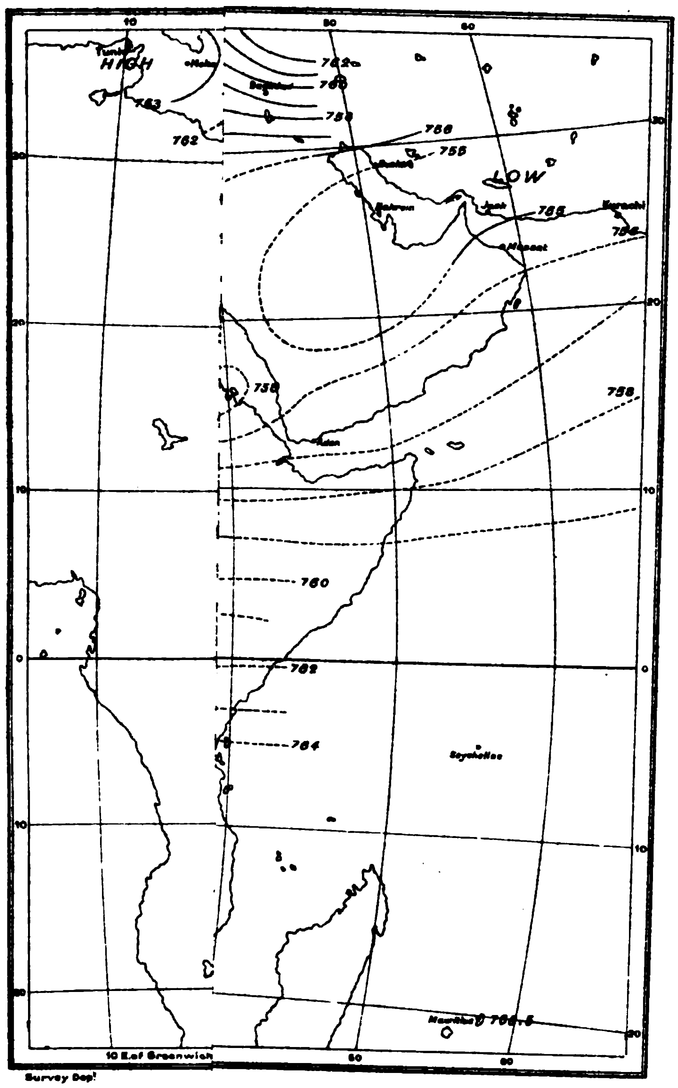
Since pressure changes are practically simultaneous over wide areas, any effect on the river gauge readings will take place in the flood two to four weeks later at Aswan, according to the distance that the water as to flow, from where the rains was falling to the point of observation and also on the velocity of the current, while at low stage the discharge is the result of the meteorological conditions in Abyssinia several months

[1] Strictly speaking, Wadelai on the Bahr el Jebel (lat. 3° N.)., which has November rains, would be within the effective basin, since there is a direct waterway from this point to the lower reaches of the Nile, but as the discharge at the mouth of this river, where it joins the White Nile, only varies but little from 300 cubic metres per second throughout the year, this rainfall has no seasonal effect on the Aswan discharges.

ESSURE

1904

PLATE XLV b.



earlier. Since, therefore, the pressure curves and river gauge curves cannot be directly compared, the mean difference of each month's gauge readings from the 32 years' mean of the readings of the Aswan gauge, will be used to show the effect of the rainfall on the river's discharge.

A comparison of these differences with the pressure anomalies on plate XLVII, will serve to show the remarkably close connection which there in most years between the variations of pressure from the normal at Beirut, Cairo and Aden, and the rainfall of Abyssinia, as represented by the gauge readings at Aswan. In one or two cases even a brief change of pressure for a month appears to be reproduced in the gauge readings, as a consequence of the increased or decreased rainfall, but though no special stress should be laid on these minor agreements, it is certainly remarkable to see how closely the two phenomena of pressure and rainfall agree in most years.

The first of the two following tables gives the monthly mean difference of the Aswan gauge readings from the mean readings of 1872 to 1901, and though these differences do not furnish as accurate a means of comparison as the volume of water discharged in each month would do, still they will not introduce any great error. In the table second the pressure anomalies for June to September are compared with the flood for the year by means or its ratio to a mean flood. This ratio has been obtained by comparing the volume discharged at Aswan between July 1 and October 31 in each year.

MEAN DIFFERENCE OF GAUGE READINGS AT ASWAN IN CENTIMETRES FROM THE MEAN GAUGE READINGS OF 1872 TO 1903.

Year	July	August	Sept.	October	Year	July	August	Sept.	October
1869	+ 46[1]	+ 39	+ 61	+ 115	1887	+ 79	+ 122	+ 77	+ 14
1870	+ 71	+ 108	+ 53	+ 95	1888	− 82	− 74	− 106	− 146
1871	+ 32	+ 57	+ 22	+ 1	1889	− 61	+ 14	+ 23	+ 4
1872	+ 88	+ 42	+ 34	+ 78	1890	− 13	+ 74	+ 46	+ 80
1873	+ 18	− 58	− 48	− 54	1891	− 5	+ 6	+ 15	+ 48
1874	+ 76	+ 124	+ 94	+ 83	1892	− 30	+ 40	+ 99	+ 121
1875	+ 13	+ 58	+ 36	+ 64	1893	− 54	+ 20	− 22	+ 51
1876	+ 93	+ 42	+ 63	+ 11	1894	+ 65	+ 72	+ 68	+ 131
1877	+ 47	− 107	− 154	− 122	1895	+ 62	+ 144	+ 41	+ 1
1878	− 24	+ 10	+ 95	+ 182	1896	+ 38	+ 2	+ 53	+ 29
1879	+ 168	+ 72	+ 44	+ 42	1897	+ 2	− 56	− 16	− 26
1880	+ 122	+ 27	− 24	− 18	1898	− 47	+ 42	+ 42	+ 55
1881	− 44	− 78	+ 28	+ 2	1899	− 52	− 144	− 152	− 194
1882	− 92	− 80	− 34	− 45	1900	− 105	− 17	− 55	− 41
1883	+ 43	+ 55	+ 22	− 3	1901	− 30	− 16	− 23	− 105
1884	− 45	− 75	− 62	− 10	1902	− 120	− 249	− 127	− 79
1885	+ 78	+ 66	− 28	− 39	1903	− 49	− 118	− 18	+ 10
1886	− 38	− 12	− 2	− 41					

[1] Ten days only.

Comparison of Pressure Anomalies, June to September, at Cairo, with the Ratios of the Nile Floods to a Mean Flood.

Year	Ratio to mean flood	Pressure anomaly[1]	Year	Ratio to mean flood	Pressure anomaly[1]
		mm.			mm.
1869	1·18	−0·67	1887	1·19	−0·47
1870	1·23	−0·12	1888	0·72	−0·06[2]
1871	1·05	−0·49	1889	1·00	−0·45
1872	1·11	−0·49	1890	1·12	−0·28
1873	0·84	+0·43	1891	1·01	+0·42[2]
1874	1·26	+0·36[2]	1892	1·20	−0·52
1875	1·10	−0·14	1893	0·99	−0·22[2]
1876	1·09	+0·16[2]	1894	1·22	−0·38
1877	0·70	+0·91	1895	1·15	+0·33[2]
1878	1·24	−0·86	1896	1·06	+0·09[2]
1879	1·14	−1·15	1897	0·89	+0·06
1880	0·98	+0·11	1898	1·07	−0·005
1881	0·93	+0·11	1899	0·63	+0·54
1882	0·84	+0·60	1900	0·89	+0·30
1883	1·04	+0·39[2]	1901	0·87	−0·09[2]
1884	0·83	+0·95	1902	0·63	+0·11
1885	0·99	+0·02	1903	0·89	+0·30
1886	0·91	+0·17			

By comparing these tables with the monthly mean pressures as given on plate XLVII it will be seen how far there has been correspondence between good floods and low pressure conditions, as well as between poor floods and high pressure conditions; the results are set forth in the following statement.

Year	Ratio of flood of year to mean flood	Pressure Conditions[3]	Nile flood at Aswan
1869	1·18	Cairo markedly low both before and during flood.	Excess all months from June to October.
1870	1·23	Cairo low up to June then normal till Aug., Sept. again low.	Moderate excess June afterwards good excess.
1871	1·05	Cairo low especially June and July.	15 July-31 August large excess, decreasing September.
1872	1·11	Cairo low in April-July, rose in Sept., falling again in Oct.	Considerable excess 20 June-15 August and again after 20 September, between these dates normal.

[1] Mean of the mean anomalies of the months June, July, August, September.

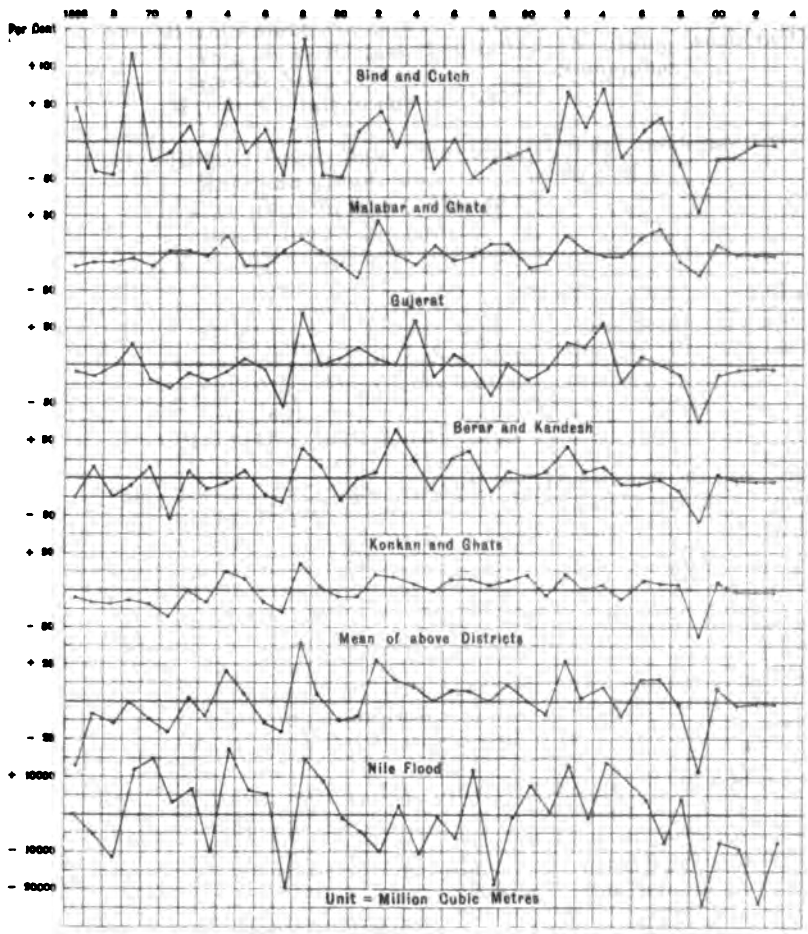
[2] Years in apparent disagreement from the rule that — anomalies coincide with floods above the average, and + anomalies with floods below the average.

[3] These are taken from smoothed curves.

PLATE XLVI.

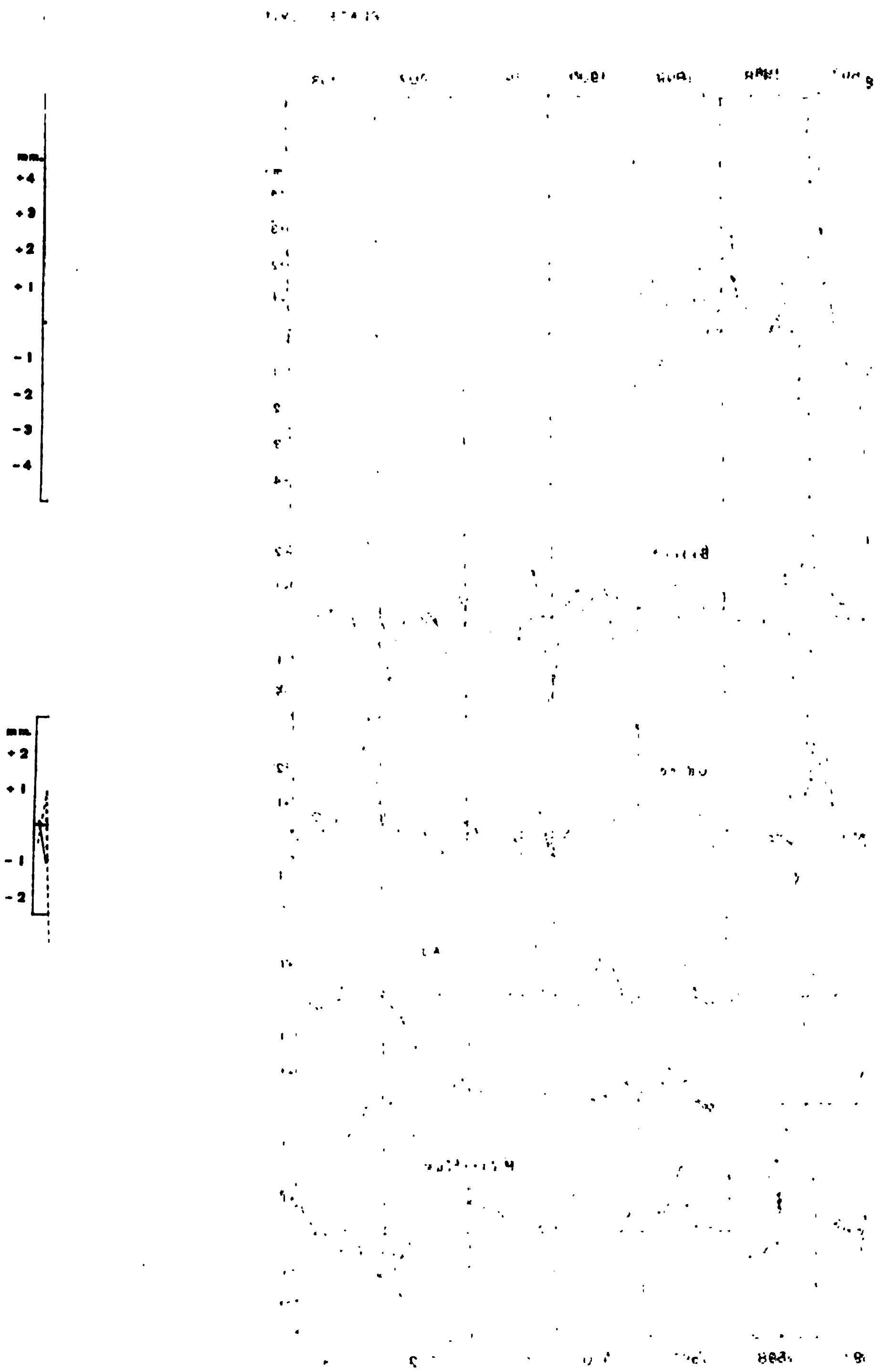
INDIAN RAINFALL

ARABIAN SEA CURRENT, PERCENTAGE VARIATION FROM MEAN OF MAY TO OCTOBER



YEAR	Ratio of flood of year to mean flood	PRESSURE CONDITIONS	NILE FLOOD AT ASWAN
1873	0·84	CAIRO low April, high May-July, lower Aug. and Sept.	15 June-5 July large excess, then large deficit especially 26 July to 10 August.
1874	1·26	CAIRO high March, April, May then fell steadily throughout rest of year.	Considerable excess from 5 June onwards.
1875	1·10	BEIRUT and CAIRO low till July; Aug. above normal, then falling till Nov. MAURITIUS fall to end of Oct.	General moderate excess after 15 June—weakened 15-25 September.
1876	1·09	BEIRUT April, May, June high, March and Sept. low. CAIRO, March, April, May low then rising to November. MAURITIUS, April-August high.	General moderate excess after 20 June.
1877	0·70	BEIRUT, above normal till Oct., May, June, July very high. CAIRO, March-May below normal; July, August, September very high. MAURITIUS, high April to Sept.	Deficient from end July especially September and October, though July had been in fair excess.
1878	1·24	BEIRUT, very high in February, low May-October. CAIRO, very high in February, low May-October. MAURITIUS, low after March.	Deficiency of low stage diminished from 15 June after July excess, flood high and late.
1879	1·14	BEIRUT, low June-September then rose, minimum June. CAIRO, low May-September then rose minimum June. MAURITIUS, low in June, July.	Large excess in low stage was maintained in flood till end of August when it became moderate.
1880	0·98	BEIRUT, low in May, otherwise above normal. CAIRO, May, June slightly below normal, rest of year above. ADEN, no observations till Aug. then above normal. MAURITIUS, high throughout year minimum in May.	Excess till 15 August then deficient. Rise of pressure corresponds with the weakening of August and September rains.
1881	0·93	BEIRUT, high April-July, low August-October. CAIRO, high April-June, low September. ADEN, high till July, then low September-November.	Deficient till end of August then moderate excess till 15 October, then normal. Earlier rains were weak till pressure fell when they rapidly improved.

Year	Ratio of flood of year to mean flood	Pressure conditions	Nile flood at Aswan
		Mauritius, high, falling steadily except for temporary minimum in April, May.	
1882	0·84	Beirut, very high January-March high June to October, low in May. Cairo, very high January-March, high rest of year. Aden, about normal. Mauritius, low minimum April, maximum just above normal July.	Deficient; very deficient 15 July-20 August. General weakness of rains, unlike India where Monsun was good.
1883	1·04	Beirut, above normal May-September, maximum July. Cairo, above normal, maximum June, July falling to normal October. Aden, normal. Mauritius, below normal.	Moderate excess July-September, with considerable excess 25 July-10 August. October moderate defect. In this year the pressure variations do not agree with the Abyssinian rains ; a flood below the average improving in September would have been expected from the pressure conditions.
1884	0·83	Beirut, low March, then high with a secondary minimum in August. Cairo, high throughout year with minima reaching to normal in April and again in December. Aden, high with minima March August and September. Mauritius, low from March to Nov. Minimum June, July.	Good low stage maintained excess till 15 June, then defect till 20 October when moderate excess occurred. Early rains, and very late rains fair, but main rains failed, and this the pressure fairly indicates.
1885	0·99	Beirut, low throughout year minimum April. Cairo, low January, February, November, December, other months normal, June above normal. Aden, observations wanting, Mauritius, February-May below, others above normal.	Defect to end of June then moderate to good excess to end of August then again defect. High pressure in June seems to have corresponded with weakness of early rains, while the July-August rains were better than might have been anticipated.
1886	0·91	Beirut, April, May above normal, rest below, minima February, June and October. Cairo, high May, July, very high June, afterwards rapid fall.	Slight defect increasing to considerable 20 July-10 August moderate excess in second half of September. High pressure corresponding to weakness of June and July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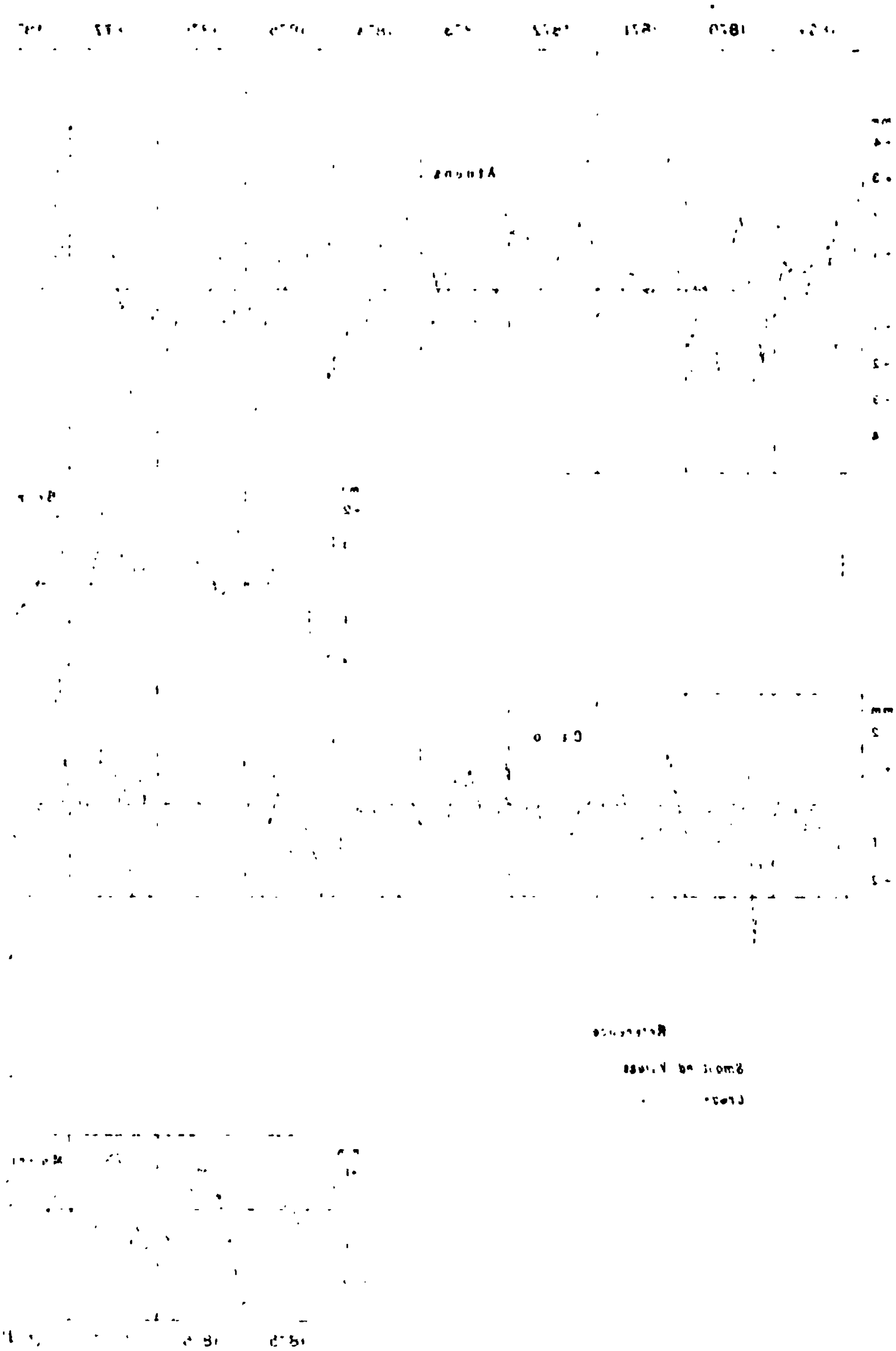

Year	Ratio of flood of year to mean flood	Pressure conditions	Nile flood at Aswan
		ADEN, low, minimum June. MAURITIUS, low March-April and July-August.	rains, gave way in August and September and so a moderate flood was obtained.
1887	1·19	BEIRUT, high till May, then low, minimum July. CAIRO, March, April high, otherwise normal or low, minimum July-September. ADEN, slight minimum in July, MAURITIUS, high, July-August. September minimum reaching normal.	Good excess rising to large from 15 July-25 August. Pressure conditions became from month to month more favourable and rains increased.
1888	0·72	BEIRUT, below normal but rising. CAIRO, below normal till August, then above. ADEN, high September. MAURITIUS, high in March then falling till October, then rising.	June moderate defect ; July, August considerable defect, becoming large after 15 Sept. The weakness of June-July rains is not well indicated by increased pressure though the increasing failure of the rains is clearly marked.
1889	1·00	BEIRUT, low from May to Sept. CAIRO, high in March, low from May to September. ADEN, low after May. MAURITIUS, high till April, then slightly above normal till October.	Defect until 15 July, then moderate excess till middle of October. High pressure in spring seems to have delayed the rains.
1890	1·12	BEIRUT, low till August, high September and October. CAIRO, low till August, high September and October. ADEN, low till July then slightly above normal. MAURITIUS, low between April and August.	June in defect, July fair excess, August, September and October good excess. The high autumn pressure does not seem to have affected the later rains, and probably did not extend far south.
1891	1·01	BEIRUT, high in February, then below normal. CAIRO, high March, low April-June then above normal July-September with fall in this last month. ADEN, above normal, maximum July then falling till Nov. ZANZIBAR, above normal Maximum August. MAURITIUS, above normal.	10 June-5 July good excess. 15 July-10 August moderate defect then normal to end of September increasing to moderate excess in October, Rains correspond with changes of pressure at Cairo and Aden closely.

Year	Ratio of flood of year to mean flood	Pressure conditions	Nile flood at Aswan
1892	1·20	Beirut, low throughout the year and falling in autumn. Cairo, low throughout the year, and falling in autumn. Aden, low throughout the year. Zanzibar, low throughout the year, minimum in June. Mauritius, very low in March then rising irregularly.	In defect till 20 June, then good excess (except 10-20 August) and after 20 September large excess. The agreement of the falling pressure with the increase of the late rains is well indicated.
1893	0·99	Beirut, March-May high, July above normal then rapid fall. Cairo, March-May very high then fall to normal and low in November. Aden, March normal, June low, August-December high. Zanzibar, rose to slightly above normal in July. Mauritius, high, maximum July, August.	June and July in defect August fair to good excess, September moderate defect, October fair to good excess. Rains correspond well with pressures; Cairo high pressure with weak June rains, then low pressure with July-August rain and the Aden high pressure in August, which was little marked at Cairo, with the September defect.
1894	1·22	Beirut, low with maximum in August. Cairo, low with maximum in April-May and September. Aden, low with maximum June, and minimum September. Zanzibar, low, minimum in September. Mauritius, moderately low, minimum February and December.	June slight excess; July-September good excess; October large excess. The rising pressure in April and May correspond with weakened May rainfall, but afterwards with decreased pressure the rains were considerably above the average and continued unusually late.
1895	1·15	Beirut, high in May, June, normal July, August, October, low September. Cairo, high April to June, then rapid fall to normal in August and minimum in December. Aden, high May, June, low July-December. Zanzibar, high May-October. Mauritius, low, max. in May.	June-September good excess, and 1-25 August large excess. In this year Cairo pressure in May, June, is not in agreement with the rainfall; after this the general rapid fall of pressure agrees with heavy rainfall.
1896	1·06	Beirut, generally above normal falling to it in Aug. and Sept. Cairo, high in March, and June-August then low September. Aden, low with a maximum above normal in August.	June small excess; July, moderate excess; Aug. considerable defect followed by fair excess. September good excess; October fair excess. Rainfall irregular till August, like the pressures.

Year	Ratio of flood of year to mean flood	Pressure conditions	Nile flood at Aswan
		ZANZIBAR, low until June then above normal. MAURITIUS, high.	
1897	0·89	BEIRUT, high till March, minimum June, then rising to very high maximum in December. CAIRO, high in March, rapid fall to normal in June-August. Very high maximum in Dec. ADEN, rather high till May, low June to September then high. ZANZIBAR, high March-July then low. MAURITIUS, high, falling towards end of year.	June, moderate excess, 25 July-25 August considerable defect afterwards moderate defect.
1898	1·07	BEIRUT, slightly below normal with minimum in October. CAIRO, generally near normal after March, low in September and October. ADEN, low. MAURITIUS, low.	1 June-10 July moderate defect. 11 July-5 August large defect. 6-31 August good excess; Sept. and October moderate excess. High pressures at Beirut and Cairo seem to have interfered with early rain, but as soon as they broke down, heavy rains ensued to which conditions were most favourable.
1899	0·63	BEIRUT, high March-December. CAIRO, high, March-December. ADEN, high, April-December. ZANZIBAR, high, April-Dec. MAURITIUS, high, May-Dec.	June, normal; July, considerable defect. August, September and October large defect. General high pressure caused exceptional weakness of rains throughout rainy season.
1900	0·89	BEIRUT, high from May to October, rapid fall in November and December. CAIRO, high in April and May, fall to normal in June, rise in August and September the rapid fall till December. ADEN, high April to August, low September to December. ZANZIBAR, above normal, highest in March. MAURITIUS, high in January-March low April-June, high July-December.	June considerable defect, July large defect; August, moderate excess, September considerable October defect. Generally insufficient rains but improved by heavy July-August rain.
1901	0·87	BEIRUT, high January to April, low May-October, minimum August.	Moderate defect to end of Septe-mber except 15-31 August when there was moderate

YEAR	Ratio of flood of year to mean flood	PRESSURE CONDITIONS	NILE FLOOD AT ASWAN
		CAIRO, high January-April, just below normal May-October. ADEN, above normal. ZANZIBAR, high except April which was just below normal. MAURITIUS, low April then rising, high July-December.	excess. October, large defect. Here rains seen to have been weak, generally.
1902	0·63	BEIRUT, slightly above normal till September then low. CAIRO, above normal with moderately high maxima in January, June and December. ADEN, low after March. MAURITIUS, low after March.	June moderate defect. July, large defect; August very large defect, September large defect, October moderate defect.
1903	0·89	High till end of June; in July August considerable fall especially at Aden, then a rise in October.	July and half August large defect, then rapid improvement to normal, and in October to fair excess.
1904	0·75	Pressure generally in excess in N.E. Africa.	Normal in June, weak in July, improved for a while but very deficient after 15 August.
1905	0·65	Pressure in marked excess over Egypt and the Sudan.	Late and very weak throughout season.

Percentage of Agreement.—Still we may say that 30 out of the 35 years, or 86 per cent, show a good agreement of — anomalies of pressure with excess of rainfall and + anomalies with a deficiency, which is sufficiently satisfactory to encourage further study; it at all events furnishes a working hypothesis which may be used to estimate the probability of a year's flood being much below or above the normal, and as knowledge advances a closer estimate may perhaps be formed.

Low Stage of Nile.—Besides the heavy rains of July and August which principally supply the Nile flood, the meteorological phenomena may also indicate conditions favourable to precipitation at the time of the later autumn rains of September and October which affect the low stage or summer supply of the river.

The connection is not so simple as in the case of the flood, for the effect of heavy autumn rains may be counteracted by the effects of a very deficient rainfall of earlier months, while an unusually copious

summer rainfall will give a good low stage supply, even though the autumn rains have been feeble.

In the next table the pressure anomalies for September and October are compared with the mean excess or defect of the March to May gauge readings at Aswan of the following year. From this it is seen that out of 34 years a negative value of the mean of the anomalies for September and October was followed by a low stage above the average, and a positive value by one below the average in seventeen cases.

If now we take the excessively high floods of 1870 and 1878, when the summer rains were sufficiently heavy to mask any effect of the positive pressure anomalies in the autumn, and also the very low floods of 1873, 1877, 1888, 1901 and 1902, when deficient summer rainfall outweighed the precipitation which may have accompanied the small negative pressure anomalies of the autumn, the cases which agree with what might be expected are 24 out of 34, or 71 per cent.; of the 11 discrepant years, 1871 and 1891, which were followed by a deficient low stage, had respectively + and — pressure anomalies in September, which month would naturally be more effective in rainfall than October.

This agreement is as good a one as can be expected where so many causes are at work, and where no data from the immediate neighbourhood are available.

Year	Mean difference from mean gauge reading for September	Pressure variation at Cairo			Flood ratio to mean flood	Mean difference from mean gauge readings of March, April, May, next year	
	Aswan	September	October	Mean		Aswan	Wadi Halfa
		mm.	mm.	mm.		cm.	cm.
1869	+ 61	−1·16	+0·75	−0·20	1·18	..	..
1870	+ 53	+0·04	+0·15	+0·10	1·23	+ 39	..
1871	+ 22	+0·34	−0·65	−0·16	1·05	− 52	..
1872	+ 34	+0·34	+0·15	+0·25	1·11	− 2	..
1873	− 48	−0·36	+0·05	−0·16	0·84	− 79	..
1874	+ 94	+0·44	+0·35	+0·40	1·26	− 4	..
1875	+ 36	+0·84	−3·05	−1·10	1·10	+ 39	..
1876	+ 63	+0·34	+0·45	+0·40	1·09	− 4	..
1877	−154	−0·26	−0·45	−0·36	0·70	− 74	..
1878	+ 95	−0·38	+0·47	+0·05	1·24	+177	..
1879	+ 44	−1·11	+0·52	−0·28	1·14	+110	..
1880	− 24	+0·14	+0·27	+0·20	0·98	− 6	..
1881	+ 27	−0·03	+0·06	+0·02	0·93	− 35	..
1882	− 34	+0·38	+0·37	+0·38	0·84	+ 20	..
1883	+ 22	−0·45	+0·68	+0·12	1·04	+ 58	..
1884	− 62	+0·98	+0·68	+0·83	0·83	− 25	..
1885	− 28	+0·08	+0·19	+0·14	0·99	− 26	..
1886	− 1	−0·11	−0·52	−0·32	0·91	− 21	..
1887	+ 77	−0·21	−0·58	−0·40	1·19	− 10	..

Year	Mean difference from mean gauge reading for September	Pressure variation at Cairo			Flood ratio to mean flood	Mean difference from mean gauge readings of March, April, May, next year.	
	Aswan	September	October	Mean		Aswan	Wadi Halfa
		mm.	mm.	mm.		cm.	cm.
1888	−106	+0·42	−0·45	−0·02	0·72	− 82	..
1889	+ 23	−0·28	+0·25	−0·02	1·00	− 67	..
1890	+ 46	+1·44	+0·97	+1·20	1·12	− 32	− 33
1891	+ 15	+0·68	−0·77	−0·04	1·01	− 48	− 45
1892	+ 99	−0·80	−0·61	−0·70	1·20	+123	+ 97
1893	− 22	−0·68	−0·25	−0·46	0·99	− 15	+ 6
1894	+ 68	−0·40	+0·27	−0·06	1·22	+104	+109
1895	+ 41	+0·92	−0·87	+0·02	1·15	+ 58	+ 56
1896	+ 53	−0·54	−0·02	−0·28	1·06	+ 66	+ 58
1897	− 16	−0·17	+0·92	+0·38	0·89	− 25	− 22
1898	+ 42	−0·17	−1·30	−0·74	1·07	+ 71	+ 52
1899	−152	+0·11	+0·31	+0·21	0·63	−128	− 68
1900	− 55	+0·69	+0·28	+0·48	0·89	− 61	− 37
1901	− 23	−0·07	−0·18	−0·12	0·87	− 76	− 39
1902	..	−0·39	+0·30	−0·05	0·63	− 85	− 53

It now remains to examine the distribution of atmospheric pressure over north-eastern Africa, and for this purpose the monthly mean values of the morning (8 a.m.) observation have been taken. During the last five years a large number of new meteorological stations have been established and at a certain number of these barometer readings are taken regularly ; moreover the levelling operations carried out by the Sudan Irrigation service during 1905 have enabled the altitude of the stations south of Khartoum to be determined, relatively to Khartoum with considerable accuracy. The isobars drawn on the basis of these observations are therefore correct within a small amount until the desert region lying west of the twenty-ninth meridian is reached and here the uncertainty commences. However the certain result is that the distribution of pressure over north-eastern Africa differs radically from that hitherto given in isobaric charts of Africa.

The altitude of Khartoum is derived from two lines of levelling carried out by the Sudan Railway Department from Wadi Halfa to Khartoum and from Suakin to the Nile during the construction of these lines. The difference between the values thus obtained was 20 feet or 6 metres, and the mean value has been taken here, giving 372 metres for the zero of the present Khartoum river gauge. [1]

[1] The Sudan Irrigation service have taken this zero to be 370 metres above Mediterranean sea level.

From the mean monthly values of the atmospheric pressure (reduced to 0° C., sea level, and lat. 45° N.) the isobaric charts on Plates XLV*a* and XLV*b* have been drawn to show the distribution of pressure in June, July, August and September for 1904. Previous to this the available stations in the Sudan were fewer and, the observations having been recently commenced, the results are not so reliable, but charts prepared from them show clearly the very pronounced trend of the isobars from north to south along the Nile valley instead of running westwards to the west coast of Africa as has hitherto been assumed, when the only observations available were those of coast stations.

The gradient which is formed in June from the Nile valley towards the Persian Gulf becomes steeper in July and August, but it does not extend westwards to any marked extent. Here over the Libyan desert is a wide area between the 5th and 25th meridians where there seems to be little change of pressure, and travellers report light and variable winds in the summer. Further west the pressure increased as we approach the centre of high pressure which lies in the neighbourhood of the Azores, and whose monthly variations of pressure are given on Plate XLVI for Ponte Delgada. This is one of the great permanent areas of high or low pressure which have been called "action centres" by Teisserenc de Bort who [1] has shown how powerfully their movement to and fro from their mean position affects the climate of the countries round, causing it to be dry and cold, or warm and moist according to the meteorological conditions caused by the relative position of these centres of high or low pressure.

Professor E. B. Garriot thinks [2] that a similar effect is caused in the United States by a change of the position of the high pressure over the North Atlantic:

"Many well-informed meteorologists are of the opinion that the next advance in the art of weather forecasting will be accomplished by a correlation of the greater and lesser areas of high and low barometric pressure of the northern hemisphere or of the globe. The forecasts now issued by meteorological services are based upon skill acquired by study, observation, and experience in calculating the development, movements, increase, and decrease in intensity, and magnitude of areas of high and low barometric pressure that appear within areas covered by the telegraphic reports of the several services. The dependence of

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[1] "Annales du Bureau Central Météorologique," Paris, 1883.

[2] Bull. 35 U. S. Dept. of Agric. Weather Bureau Long Range Weather Forecasts, by E. B. Garriott.

these lesser high and low areas upon the greater or continental and oceanic so-called permanent areas of high and low barometric pressure is recognized, and the fact is admitted that a knowledge of the character and movements of the greater masses of the earth's atmosphere, as represented by the continental and oceanic seasonal high and low areas, is essential to calculations of weather conditions in any given section or locality for periods greater than two or three days in advance. For it is apparent that upon the exact location and magnitude of these greater high and low areas for a day, week, month, or season does the character of the weather in the regions which they dominate depend. For instance a slight shifting to the westward of the summer North Atlantic high pressure area gives unusual heat and generally dry weather over the eastern portion of the United States. If the centre of the high area shifts to the westward, south of its usual position as regards latitude, the heat is general from the Gulf of Mexico to Canada; if the centre occupies a more northern latitude in its western position the heated area is confined to the more northern districts of the eastern portion of the United States, and the South Atlantic States receive the benefit of easterly winds from the ocean. When the Atlantic high area occupies an easterly position over the ocean, or exhibits pressures below the normal, cool weather for the season or at least variable temperatures, are experienced over the eastern portion of the United States. In fact, the North Atlantic high area controls to a great degree not only the summer weather of the greater part of the United States, but also the course and character of West Indian hurricanes."

It is therefore of importance to determine the distribution of pressure over North Africa in the summer months in the light of the recent observations which are represented in Plates XLV*a*, and XLV*b*. Any representation of it at the present time can only be provisional since observations are few in the most important region, viz. between lake Chad and Timbuctu, and no altitudes are accurately known. A distribution which appears to be possible, if not also probable in July, so far as data at present exist is shown on Plate XLVIII, where an area of low pressure is shown lying in the neighbourhood of lake Chad.

The evidence for its existence may be stated briefly as follows.

1. The isobar representing 759 millimetres of pressure lies at a short distance to the west of the Nile and probably that of 760 also;

2. The 760 millimetres isobar also lies near the west coast of North-Africa and north-coast of the Gulf of Guinea, as determined by observation at coast stations;

3. The winds of the central and western Sahara according to travellers accounts tend to converge towards this region;

4. The mean direction of the winds of the Nile Valley both north and south of Khartoum do not show nearly so pronounced a westerly component as would be expected from the pressure gradient;

5. In the basins of the Bahr el Jebel and Bahr el Ghazal the easterly component of the southerly winds in the summer months is strongly marked.

If further study should confirm this hypothesis, it will follow that a displacement of the high pressure West of Africa may affect the meteorological conditions very differently according to whether it moves eastwards over the Mediterranean or south-eastwards towards the southern Sahara, and such a low pressure area must affect by its variation the southerly winds which accompany the summer rains of the region to the south.

Thus the situation is that there exists a certain relation between increase and decrease of pressure over northern and north-eastern Africa and the deficiency or abundance of rainfall on the Abyssinian tableland; that the movement of the high pressure action centre of the Azores eastwards (Plate XLVIII) in any summer will cause an increase of pressure over Northern Africa, producing conditions less favourable to precipitation in Abyssinia. A detailed study of the pressure conditions existing from the Azores to the Arabian sea and their comparison with the Nile floods of the last 15 years is the next step in the investigation of this matter, but this is beyond the scope of the present volume. [1]

Possibility of Flood Prediction.—The present hypothesis seems to furnish a more satisfactory basis for predicting the character of the Nile floods when it is used in conjunction with the indications of the Indian south-west monsun, as they are construed by the Meteorological Department in India, than most of the proposals which have been previously made.

Mahmoud Pasha El Falaki, in a paper[2] read before the Khedivial Geographical Society at Cairo, January 6, 1882, suggested that the Nile flood might be predicted by a study of the temperatures and barometric pressures observed at Cairo, and as he was under the impression that the White Nile furnished a considerable part of the flood, he proposed to consider the meteorological conditions in February, March, and April as furnishing a guide to the probability of an excess or deficit

[1] This is now in hand.
[2] "Bull. Soc. Khéd. Géog." February 6, 1885, p. 327,

of equatorial rainfall, and those of July as indicating the conditions on the Abyssinian plateau. Having taken the spring months, he was led to consider that a high temperature and a low pressure coincided with the low flood, and a low temperature and high pressure with a high flood basing his view on the years 1870 to 1881.

Ventre Pasha,[1] in a paper on the hydrology of the Nile, discusses the possibility of predicting the flood, and concludes that the knowledge of the force and direction of the winds in the neighbourhood of Aden and Zanzibar should furnish a basis for satisfactory forecasting. He refers to some investigators who have endeavoured to trace a connection between the Nile flood and the barometric pressure and temperature at Cairo, but that such a relation is possible he denies, apparently on the ground that the distance between the equatorial lakes and Cairo is over 3500 kilometres, and consequently too great for meteorological phenomena at the two places to have any relation to one another; but it is with the Abyssinian plateau some 2200 kilometres distant that we have to do, and also variations of barometric pressure are frequently found to occur over as great and even greater areas.

Ventre Pasha also speaks of what he considers to be a law[2] viz., that a low flood is followed by a low summer supply, but this is only a natural sequence, since a low flood means insufficient rainfall on the Abyssinian area, and consequently the September rains are likely to be also below the average. Therefore the springs and streams will run low or dry sooner than in wetter years, and the Sobat and Blue Nile, the two variable factors of the summer or low-stage supply, will be furnishing but little. On the other hand, it will sometimes occur that a season of deficient rainfall may improve towards the end, as was the case in 1903, when the increased rainfall in the autumn provided a good low-stage supply for 1904.

It is, therefore, rather on the amonnt of rain falling at the end of the rainy season in Abyssinia, and its continuance into the autumn months, that a good low-stage supply depends; the Sobat keeps up the level of the White Nile with the water it brings from the high-lands of Kaffa, and the Blue Nile is fed by its tributaries in Gojam and Wallega. In 1903, the Blue Nile was discharging nothing at Khartoum on the 8th, 15th, and 23rd of May, after the deficient rainfall of 1902.

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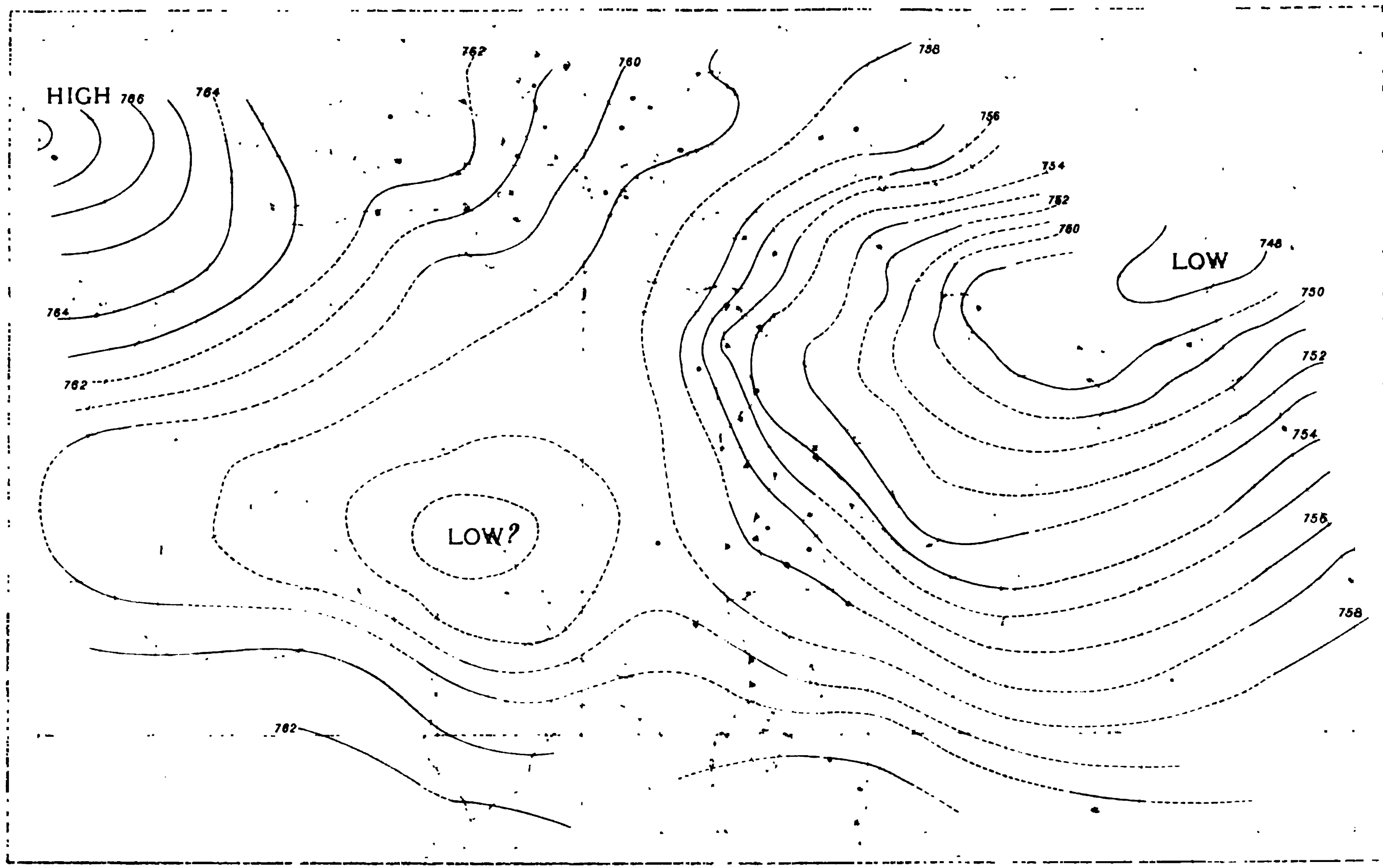
[1] Bull. Soc. Khéd. Géog., January, 1894, Cairo.
[2] Loc. cit., p. 41.
[3] The Aswan Reservoir and Lake Moeris, London, 1904; and Soc. Khéd. Géog., January 1904

MEAN ATMOSPHERIC PRESSURE JULY.

PLATE XLVIII.



Sir W. Willcocks,[3] in his paper on the Wadi Rayan, refers incidentally to the prediction of the Nile floods, and considers that good floods coincide with high humidity in June, and with a prevalence of southerly winds in April and May at Cairo; also that deficient floods are heralded by exceptional dryness in June and few southerly winds in April and May.

In the 33 years—1870 to 1902—the mean relative humidity in June is not of any real value as a guide in prediction, since out of 19 years in which the relative humidity in June was above the mean, 9 floods were below the average, and 10 were above it; and of 13 years in which the humidity was below the mean, 8 floods were above the average and 5 were below it.

Turning now to the southerly winds, the number of observed winds of which the direction was south of east or west (from some part, that is, of the southern half of the horizon) has been taken from the 3-hourly observations at Abbassia (near Cairo). In 9 years, when the flood was *above* the average, the southerly winds were above the average in 5 years and below it in 4 years. In 7 years having floods *below* the average the southerly winds were below the average in 4 years and above it in 3 years.

It cannot therefore be said that either the mean relative humidity in June or the prevalence of southerly winds in April and May are safe guides in predicting the Nile flood; the proposed relation will be found to hold occasionally, as in 1902; when there were few southerly winds and a large deficiency in the flood, also in 1892 was a high Nile, and the June relative humidity was also high, but in no sense can they be considered as satisfactory bases for regular prediction.

It has been pointed out[1] by the Meteorological Reporter to the government of India that, so far as records extend, excessive rainfall at Zanzibar has been followed by deficient rainfall in June in the area affected by the Arabian Sea branch of the monsun current. This sub-equatorial rainfall is most probably due, not to a diversion of the south-east trade winds but to an ascensional movement. It is hardly doubtful that the Abyssinian rainfall will be simil.rly affected but this matter demands further study.

In the following table the April rainfall at Zanzibar is compared with the June rainfall in Abyssinia which is approximately represented by the July gauge readings at Aswan, while the May rainfall is compared with the August river levels at Aswan.

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[1] Walker, Memoranda on Monsuns of 1904 and 1905, Simla 1904, 1905.

YEAR	Zanzibar [1] April	Aswan [2] Gauge July	Zanzibar [1] May	Aswan [2] Gauge August	Zanzibar [1] April+May	Ratio of Flood to Average
1877	− 48	+ 47	−131	−107	−189	0·70
1878	+ 85	− 26	−106	+ 10	− 21	1·24
1879	..	..	..	..	..	1·14
1880	+ 15	+122	−120	+ 27	−105	0·98
1881	−140	− 44	+ 45	− 78	− 95	0·93
1882	− 36	− 92	− 8	− 80	− 44	0·84
1883	− 22	+ 43	− 74	+ 55	− 96	1·04
1884	− 70	− 45	+ 78	− 75	+ 8	0·83
1885	..	..	..	..	..	0·99
1886	..	..	..	..	..	0·91
1887	..	..	..	..	..	1·19
1888	..	..	..	..	..	0·72
1889	+233	− 61	−195	+ 14	+ 38	1·00
1890	..	..	..	..	..	1·12
1891	..	− 5	+136	+ 5	+136	1·01
1892	−138	− 30	− 24	+ 40	−162	1·20
1893	+ 56	− 54	+ 44	+ 20	+100	0·99
1894	−228	+ 65	− 7	+ 72	−235	1·22
1895	−174	+ 62	− 63	+143	−237	1·15
1896	− 65	+ 38	+ 17	+ 2	− 48	1·06
1897	+172	+ 2	+ 52	− 56	+224	0·89
1898	−273	− 87	−171	+ 42	−344	1·07
1899	+214	− 52	+231	−144	+445	0·63
1900	+ 55	−105	− 6	+ 17	+ 49	0·89
1901	+142	− 30	+185	− 16	+327	0·87
1902	− 69	−120	+ 48	−250	− 21	0·63
1903	− 17	− 9	− 41	− 67	− 58	0·89
1904	+ 52	− 22 [3]	+281	− 39 [3]	+333	0·75
1905	+457	−124 [3]	+ 1	−164 [3]	+458	0·65

It will be seen that almost without exception, excess of subequatorial rainfall was followed by low levels of the Nile flood. The reverse is not so invariable for while deficient rainfall in such years such as 1892, 1894, and 1898 was followed by good and even high flood, in other years similar deficiency was the result of a general weakness of rainfall in this part of Africa as in 1881, 1902 and 1903.

Summary.—We have seen therefore that, when the Nile floods are examined for a period of about 175 years during which the records have all the appearance of being comparable and reliable, no regular alternation of high and low floods is to be found.

Turning to the meteorological conditions, atmospheric pressure in north-eastern Africa appears to vary inversely as the rainfall of Abys-

[1] Excess or defect of rainfall in millimetres.
[2] Excess or defect in centimetres of mean gauge reading of month.
[3] Wadi Halfa gauge readings used.

sinia, and a similar relation between pressure and rainfall has been demonstrated in other parts of the globe. The distribution of pressure in the summer months in the light of recent information shows that the Asiatic low pressure in the monsun season is abruptly terminated about the meridian of the Nile valley and to the west of this there is probably an area of almost equal pressure intervening between it and the high pressure of the Azores-action centre while in summer a low pressure area may lie to the south-west. The encroachment of this high pressure on the eastern part of North Africa may produce there the unfavourable conditions of high pressure which have been recognized as coinciding with deficient rainfall on the Abyssinian tableland, while conversely its withdrawal so as to allow of deepening or extension of the low pressure trough probably acts favourably towards the conditions of precipitation in Abyssinia.

It seems that the two principal factors to be considered are firstly the strength of the south-east trade winds as they progress from the south to the north of the equator, along the eastern coast of Africa, and secondly, the excess or defect of atmospheric pressure in the area represented by Aden, Cairo, Beirut and the region lying to the west of this; the subequatorial rainfall in early summer must also be considered.

So far as our knowledge goes at present it may be said that:—

1. Generally speaking the curve of Nile floods varies inversely as the mean barometric pressure of the summer months, high pressure accompany low floods, and low pressures accompany high floods.

2. These pressure variations show a great similarity over wide areas, but seem to be to some extent dependent upon the position of the Azores high pressure "action-centre."

3. Taking the monthly means of atmospheric pressure, this relation is even more clearly shown, and pressure above or below the normal in months of the rainy season of Abyssinia coincides closely with deficiency or excess of rainfall,

4. Taking the 37 years—1869 to 1905—in 6 years out of 7 a veuy fairly accurate prediction of the flood from month to month could have been made, and there seems a reasonable probability that further and more detailed study of the conditions above described may increase the reliability.

5. The effect of excessive subequatorial rainfall in April and May in the neighbourhood of Zanzibar seems to have a distinctly prejudicial effect on Abyssinian rains.

NDIX I.

ON TABLES.

es to Inches.

	50	60	70	80	90
	5·9	6·3	6·7	7·1	7·5
	9·8	10·2	10·6	11·0	11·4
	13·8	14·2	14·6	15·0	15·4
	17·7	18·1	18·5	18·9	19·3
	21·7	22·0	22·4	22·8	23·2
	25·6	26·0	26·4	26·8	27·2
	29·5	29·9	30·3	30·7	31·1
	33·5	33·9	34·3	34·6	35·0
	37·4	37·8	38·2	38·6	39·0

to Yards.

	50	60	70	80	90
1	164·0	175·0	185·9	196·9	207·8
5	273·4	284·3	295·3	306·2	317·2
8	382·8	393·7	404·6	415·6	426·5
2	492·1	503·1	514·0	524·9	535·9
6	601·5	612·4	623·4	634·3	645·2
9	710·9	721·8	732·7	743·7	754·6
3	820·2	831·2	842·1	853·0	864·0
7	929·6	940·5	951·5	962·4	973·3
0	1039·0	1049·9	1060·8	1071·8	1082·7

es to Miles.

	50	60	70	80	90
0	93·2	99·5	105·6	111·9	118·1
1	155·3	161·6	167·8	174·0	180·2
3	217·5	223·7	229·9	236·1	242·3
4	279·6	285·8	292·1	298·3	304·5
5	341·8	348·0	354·2	360·4	366·6
7	403·9	410·1	416·3	422·5	428·8
8	466·0	472·2	478·5	484·7	490·9
0	528·2	534·4	540·6	546·8	553·0
1	590·3	596·5	602·7	608·9	615·2

s to Square feet.

	50	60	70	80	90
·1	1614·8	1722·4	1830·1	1937·7	2045·4
·6	2691·3	2798·9	2906·6	3014·2	3121·9
·1	3767·8	3875·4	3983·1	4090·7	4198·4
·6	4844·3	4952·0	5059·6	5167·3	5274·9
·2	5920·8	6028·5	6136·1	6243·8	6351·4
·7	6997·3	7105·0	7212·6	7320·3	7427·9
·2	8073·8	8181·5	8289·1	8396·8	8504·4
·7	9150·3	9258·0	9365·6	9473·3	9580 9
·2	10226·9	10334·5	10442·2	10549·8	10657·5

undreds of cubic feet per second.

	500	600	700	800	900
	177	212	247	283	318
	530	565	600	636	671
	883	918	954	989	1024
	1236	1271	1307	1342	1377
	1589	1624	1660	1695	1730
	1942	1978	2013	2048	2084
	2295	2331	2366	2401	2437
	2649	2684	2719	2755	2790
	3002	3037	3072	3108	3143
	3355	3390	3426	3461	3496

Comparison of thermometric scales

Centigrade	Fahrenheit
0°	32°0
1	33·8
2	35·6
3	37·4
4	39·2
5	41·0
6	42·8
7	44·6
8	46·4
9	48·2
10	50·0
11	51·8
12	53·6
13	55·4
14	57·2
15	59·0
16	60·8
17	62·6
18	64·4
19	66·2
20	68·0
21	69·8
22	71·6
23	73·4
24	75·2
25	77·0
26	78·8
27	80·6
28	82·4
29	84·2
30	86·0
31	87·8
32	89·6
33	91·4
34	93·2
35	95·0
36	96·8
37	98·6
38	100·4
39	102·2
40	104·0
41	105·8
42	107·6
43	109·4
44	111·2
45	113·0
46	114·8
47	116·6
48	118·4
49	120·2
50	122·0

Centigrade Fahrenheit

APPENDIX II.

BIBLIOGRAPHY.

A LIST OF SOME BOOKS AND PAPERS WHICH BEAR ON THE PHYSIOGRAPHY OF THE NILE BASIN.

ABBREVIATIONS.	EXPLANATIONS.
G. J.	Geographical Journal.
P. R. G. S.	Proceedings of the Royal Geographical Society.
J. R. G. S.	Journal of the Royal Geographical Society.
B. S. G.	Bulletin de la Société de Géographie, Paris.
P. M.	Petermann's Geographische Mitteilungen, Gotha.
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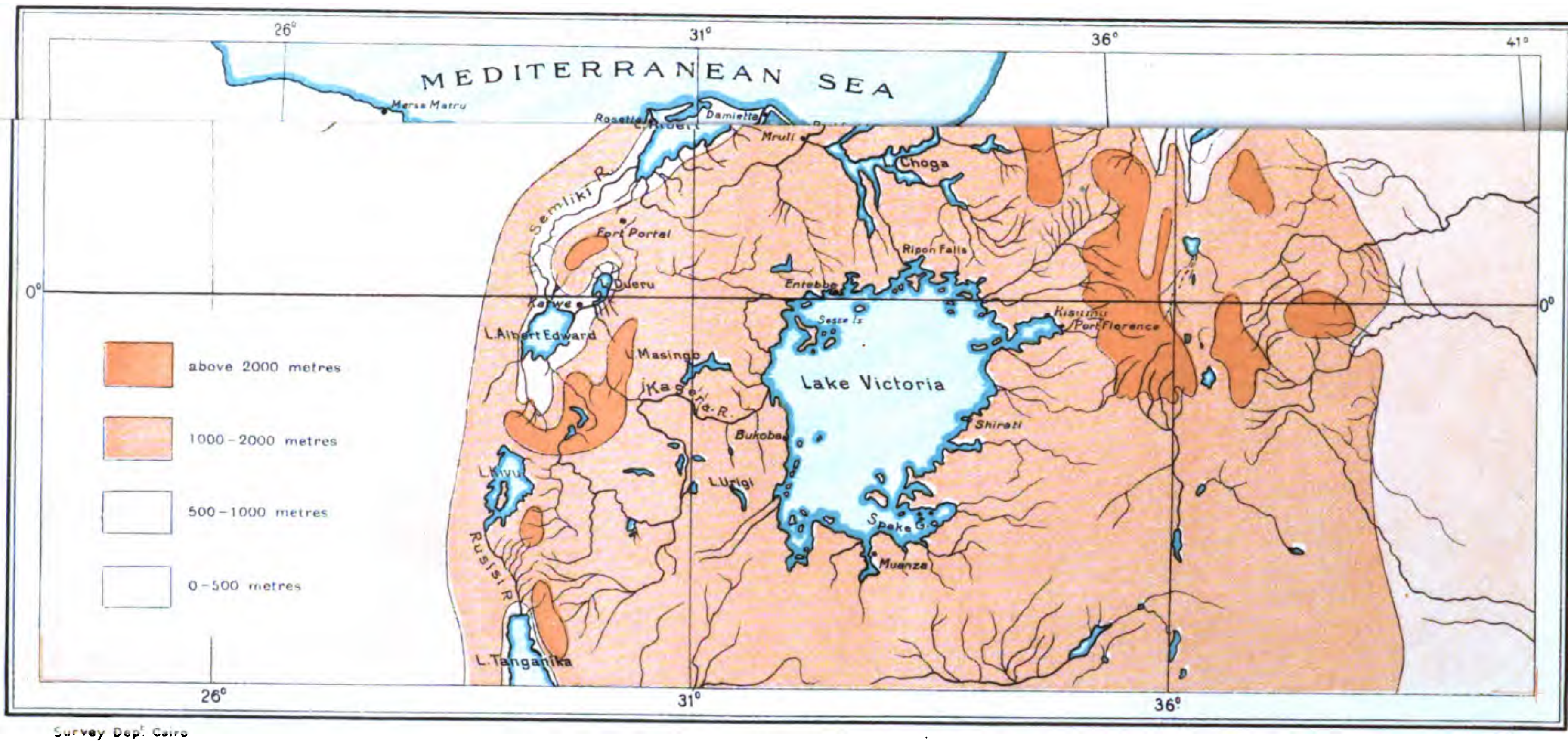
215. **Wilson, Captain H.**—*A trip up the Khor Filus and country on the left bank of the Sobat*, G. J. Oct. 1902.

216. **Zöppritz K.**—*E. de Pruyssenaere's Reisen und Forschungen im Gebiete des Weissen und Blauen Nil*, Pet. Mitt. Erganzungsheft No. 51, Gotha, 1877.

MAP OF THE NILE BASIN



Scale 1 : 7,500,000

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LIST OF MAPS AND PLANS

Published by the Survey Department, and on sale at the Offices of the Survey Department, Giza, and the Geological Museum, Cairo.

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Qaliubia " " $\frac{1}{2500}$	050	065
Daqahlia " " $\frac{1}{2500}$	050	065
Giza " " $\frac{1}{4000}$	050	065
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Aswan " " $\frac{1}{2500}$	050	065
Girga " " $\frac{1}{2500}$	050	065
Assiut " " $\frac{1}{2500}$	050	065
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Port Said — 1 " $\frac{1}{5000}$	120	—
Girga. — in the press.	—	—
Sohag — in the press.	—	—
Tanta. — in the press.	—	—

LIST OF PUBLICATIONS

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PUBLIC WORKS MINISTRY.	
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